HOBBLE

An Experimental Study of Phase Transformers

Electrical Engineering
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1901

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AN EXPERIMENTAL STUDY OF PHASE TRANSFORMERS AND TRANSFORMATION

By

Arthur C. Hobble

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE IN

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UNIVERSITY OF ILLINOIS

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OF Bachelor of Science in Electrical Engineering.

Wm S. Aldrich

HEAD OF DEPARTMENT OF Electrical Engineering

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PERFACE.

No attempt has been made in this thesis to cover the whole field of Phase Transformation. In fact, only a very small portion of the subject is treated. Chapter IX. is the essence of the thesis as far as real experimental work is concerned. This chapter takes up in detail the different characteristics of the synchronous converter as a phase transformer. Not all of the phase combinations outlined were tried owing to lack of time.

Considering the number of operations that may be performed with a synchronous converter it is a remarkably useful machine. A new line of investigation[#], carried out by the author in accordance with the suggestions of Mr. Ludwig Gutmann, Consulting Electrical Engineer of Peoria, Ill., is also treated in ChapterIX. Mr. Gutmann's idea was to operate a double-current generator or synnhronous converter as a one to three-phase transformer by applying single-phase current to the commutator end of the armature and taking out three-phase currents at the slip-ring end. The operation is successful when the transforming device is rotated mechanically but no machine has as yet been constructed which will start itself when the single-phase current is applied at the commutator end.

Mr. Gutmann's plan was extended to a two-to three-phase transformation in the same manner, as described in Chapter IX. The experiment did not prove successful but it was not demon-

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[#]. On the Production of Rotary Magnetic Fields by a Single-Alternating Current, Ludwig Gutmann . American Institute of Electrical Engineers, vol. 11, Dec. 19, 1894.

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strated to the satisfaction of the author that it could not be carried out. The Chapters on development,design,construction and applications of phase transformers are necessarily brief. Concerning these features of the subject a list of books and references is given which may be consulted.

The following may be considered as the essential points brought out in the investigation of the synchronous phase converter:

1. The efficiency of transformation is rather low.
2. The machine is not economical when used simply for phase transformation.
3. The voltage regulation is poor.
4. Auxilliary starting devices are necessary unless direct-current is supplied.
5. The machine may however be operated economically when used as a rotary converter as well as a phase transformer.
6. The input power factor can be adjusted by varying the excitation. Unity power factor is possible at any load.

SYLLABUS.

PHASE TRANSFORMERS AND TRANSFORMATION.

I. Development of Phase Transformers and Transformation.

1.-On the phase transformation of electrical energy;methods;etc.

2.-Historical development:-types of phase transformers.

3.-Reversibility of phase transformations;exceptions!

II. THEORY AND PRINCIPLES OF PHASE TRANSFORMATION.

1.-General principles;(a) static and rotary transformers.

2.-Relation between phase transformers and similar apparatus for other purposes,within the same classification.

3.-Armature inductance and reactions in rotary types.

III. CLASSIFICATION.- (A.I.E.E. Rep.Com.on Standardization).

1.-General:Synchronous commutating machines or converters.

Excitation:separately excited,or self excited;examples.

"Aconverter is a rotary device for transforming electric energy from one form into another without passing it through the intermediary form of mechanical energy."

2.-General: Stationary induction apparatus:- "Stationary apparatus changing electric energy from one form into another, without passing it through an intermediary form of energy."

Special:- Transformer in which primary and secondary coils are electrically insulated from each other.

Subdivission:- Phase transformers; polyphase to polyhhase or polyphase to single-phase transformation; and vice versa;exampes

3.-General:- Rotary induction apparatus,-primary and secondary windings rotating with respect to each other.

Special:- Rotary phase converters:examples.

IV. DESIGN. (General and Special according to type.)

1.-Allowances,constants,coefficients.

2.-Electrical and magnetic circuits,details and windings.

3.-Mechanical and structural details.

4.-Selection of type of phase transformer for give service.

V. ECONOMY OF PHASE TRANSFORMATION,-POLYPHASE vs.SINGLE-PHASE AS Related to;

1.-Electric Transmission

(a) Relative weight of copper required for the various systems.

(b) Losses due to ohmic and reactive drop,leakage, capacity.

2.-Alternating Current Regulation.

(a) As to installation of system;effect of location.

(b) Effect of alternating current networks.

(c) Methods of regulating alternating current drop.

(d) Losses due to inductance,capaci y,resistance,leakage.

3.-Distribution;value of polyphase network.

(a) Two-wire vs.three-wire.

(b) Two-phase three wire vs. four wire system.

(c) Three-phase three-wire vs.four wire system.

(d) Monocyclic system of distribution.

4.-Utilization of Alternating Current electric energy.

VI. CONSTRUCTION According to type.

1.- Synchronous phase transformer.

(a) Electrical details;windings,connections at alternating Current end,single and polyphase circuits;relations of phase;number of poles; insulation.

(b) Magnetic considerations:laminations of armature-cores and poles.

(c) Mechanical and structural details and accessories.

(d) Limitation upon frequency and voltage imposed by construction.

(e) Description of machines in commercial use.

2.- Stationary induction phase transformers.

(a) Electrical details,windings,connections for different systems,insulation.

(b) Magnetic considerations;lamination of cores,dimensions.

(c) Mechanical and structural details and accessories.

(d) Limitation upon frequency and voltage imposed by construction.

(e) Description of different types of apparatus in use.

3.- Rotary induction phase transformer.

(a) Electrical details,windings,insulation and etc.

(b) Magnetic considerations,lamination of cores.

(c) Mechanical and structural details;static and dynamic balance of rotary part.

(d) Description of machines in commercial use.

(e) Accessories:

Phase-splitting devices,starting and switching in arrangements,variable speed control.

VII. OPERATION..According to type.

1.- General operating combinations.

(a) One to two-phase and vice versa.

(b) One to three-phase and vice versa.

(c) Two to three-phase and vice versa.

2.- Relation of operating conditions to phase transformation.

(a) Output relations for various phase combinations.

(b) Relation of composite transmission to phase transformation.

3.- Synchronous phase transformer.[*]

(a) Starting;as direct current motor,as alternating current induction motor,by independent motor.

(b) Functional working,reversibility.

(c) Best operating conditions.

(d) Faulty working and remedies;"pumping;" hunting.

(e) Influence of frequency upon operation.

(f) Regulation of input and output.

4.- Stationary induction phase transformer.[*]

(a) Functual working,reversibility.

(b) Connections for different systems.

(c) Effect of varying impressed E.M.F.

(d) Faulty working and remedies.

(e) Influence of variable frequency upon operation.

(f) Regulation,control of voltage;effect on lighting circuits.

(g) Ageing of the iron in core.

(h) Ratio of transformation.

(i) Heating of transformer;cooling devices.

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[*] Rotary Converter Working. same.as.above.Schedule 220,pp.67, 68,69.1900.

[*] Transformer Operation. Profs. W.S.Aldrich and W.H.Browne. Electrical Engineering Laboratory Manual,University of Illinois. Schedule 210,pp. 57, 58, 1900.

5.- Rotary induction phase transformer.*

(a) Starting;effect and value of starting devices;current.

(b) Functional working;normal and overload conditions.

(c) Effect of varying impressed E.M.F. on starting and operation loaded.

(d) Relative capacities of transformers as operated under different phase conditions.

(e) Faulty working and remedies.

(f) Influence of slip upon the frequency of phase transformation.

(g) Ingluence of frequency and variable speed.

(h) Regulation,control of voltage; effect on lighting circuits.

VIII. PERFORMANCE AND TESTING.According to type.

1.- Synchronous phase transformer.

(a) Principles,methods; errors,precautions,precision of measurements.

(b) Effect of variables on performance;voltage,frequency,excitation,character and amount of load,wave form and etc.

(c) Voltage regulation and ratios.

(d) Phase relations and characteristics,influence of excitation.

(e) Efficiency of, and losses of machine operated under various conditions.

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*. Transformer Operation. Profs. W.S.Aldrich and W.H.Browne.Electrical Engineering Manual,University og Illinois.Schedule 210 pp.64, 65, 66. 1900.

(f) Magnetic determinations; leakage, distribution and magnetization.

(g) Armature resistance, inductance and reactions.

(h) Special studiesof machine, in various relations and services.

2.- Stationary induction phase transformer.

(a), (b), (c) same as for VIII. 1.

(d) Phase relations and characteristics.

(e) Efficiency of, and losses of transformer operated under various conditions.

(f) Magnetic determinations; leakage, distribution and magnetization.

(g) Resistance, inductance, and reactions.

(h) Special studies of apparatus, in various relations services.

3.- Rotary induction phase transformer.

(a) Principles and methods employed; electrical, magnetic, mechanical.

(b) Errors, precautions, precision of measurements.

(c) Effect of variables on performance; voltage, frequency, phase shifting.

(d) Functional performance; characteristics, losses, efficiency and etc.

(e) Special studies of the rotary induction phase transformer.

IX. APPLICATIONS. According to type. (See VII. 3, 4, 5,)

As related to:

1.- Electric Transmission.

2.- Alternating Current Regulation.

3.- Distribution.

4.- Utilization of Alternating Current electric energy.

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00769	Resistance, induction, measurements, and characterics
0077	Loss, measurements, efficiency and duty.
00771	General loss measurements.
00722	Stray power.
007721	General stray power, determination.
007722	Friction and mechanical losses.
007723	Iron,(core) magnetic losses, hystereses.
007724	Eddy current losses.
007725	Copper losses.
00773	Efficiency determinations.
007731	General considerations of efficiency.
007732	Electrical efficiency.

537.8386007733	Commercial efficiency.
007735	Mechanical measurements of efficiency and losses.
0077355	By absorption dynamometer, transmission dynamometer.
0078	Results, tables, curves, conclusion of ftests, etc.
0079	Reports of tests, experiments, researches, investigations
0007	Codes, rules, regulations.
00072	National electric code.
008	Installation, accessories, individual and aggregate.
0082	Starting devices.
0083	Commutating and collecting devices.
0084	Rectifing devices.
0085	Protection and safty devices.
0086	Regulating and controlling devices.
0087	Measuring instruments.
0088	Distributive arrangements, switchboards, etc.
0089	Miscellaneous.
839	Applcations of dynamo-electric machinery, static and rotary transformers.
8391	General .
8392	Lighting service, chiefly single and polyphase.
8393	Power transmission, chiefly for this phase transmission.

AN EXPERIMENTAL STUDY OF PHASE TRANSFORMERS AND TRANSFORMATION.

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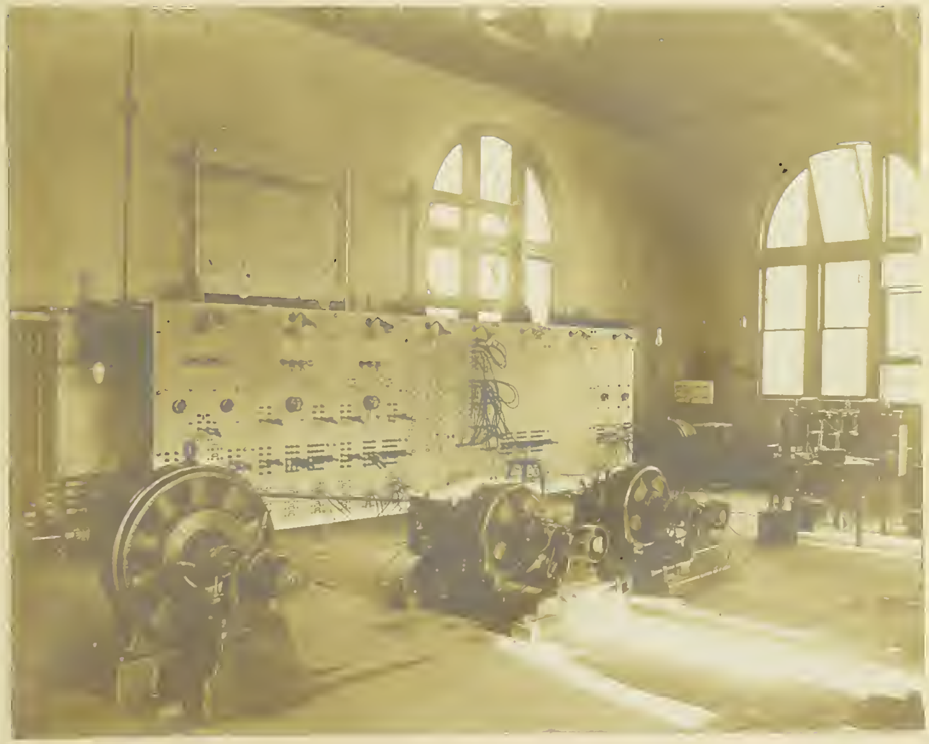

View in Electrical Engineering Laboratory, Showing Two General Electric Rotaries, Westinghouse O.D. Transformer and Regulator, and Switchboard.

CHAPTER I

DEVELOPMENT OF PHASE TRANSFORMERS AND TRANSFORMATIONS.

Art.1 The Phase Transformation of Electrical Energy is an important consideration in the transmission and subsequent distribution of electrical energy in the form of alternating currents. It is often desirable, especially from an economic standpoint to change from single-phase to polyphase or from one polyphase system to another. If there is a generating station supplying single-phase or two-phase currents at a pressure of 2200 volts to be transmitted to a point several miles distant for distribution at the same pressure, it is modern practice to transmit at a considerably higher pressure as 11000 or 22000 volts over a three-phase line as is done at Niagara.

To transform from single-phase or two-phase to three-phase or vice versa, it becomes necessary to adopt methods with either static or rotary apparatus embodying some particular application of fundamental principles by which this may be accomplished.

The various methods of phase transformation employed will be taken up more in detail later.

2. Historical Development; types of phase transformers.-- It is difficult to state the exact date at which the commercial develpoment of phase transformers and transformation took place. It may be said, however, that the theoretical and experimental development began at the time of Faraday's experiments on electromagnetic induction. His researches paved the way for future

investigation of polyphase systems.

In recent years the development of the theory of polyphase currents and phase transformation has been brought about chiefly through the efforts and experimental work of Tesla and Ferrares. In 1888, they made a publication concerning their discovery of the properties of polyphase currents. "Without this discovery, electrical engineering progress would probably have been directed into continuous rather than alternating current channels."

There are two distinct types of phase transformers, namely: static and rotary. In the former type the primary and secondary do not move relatively to each other, in the latter either the primary or the secondary rotates with respect to the other. In some instances, however, a rotary transformer might be used as a static transformer if of the induction type.

3. Reversibility of Phase Transformations.-All rotary and nearly all static phase transformers in commercial use today, may be reversed. As an instant of reversibility of a static transformer we have the Scott system of transformation from two to three phase and vice versa. In the case of a synchronous type of totary transformer, one or two-phase currents maybe supplied at one set of slip rings and three phase currents taken from another set of slip rings or vice versa. The reversibility of phase transformation depends on each particular case upon the construction of the transforming apparatus or device. More will be said in regard to this feature under chapters on classification and construction of phase transformers. Reversibility of phase transformation involves appredíable alteration or change of efficiency in the process. In the investigation presented by this thesis no reversal of transformation was taken into account from lack oftime.

CHAPTER II.

THEORY AND PRINCIPLES OF PHASE TRANSFORMATION.

4. General Principles; static and rotary transformers.-

In a polyphase system where one current lags or leads another the currents are said to be out of phase, or there is a difference of phase. A single phase system is one with one wave of energy,a polyphase system is one with several waves of energy.[1] In a single -phase system we can resolve the E.M.F's into components in quadiature with each other or into other phase relations. By the insertion of a resistance coil in a single phase circuit containing a non-inductive resistance, two E.M.F's are produced approximately in quadriture with each other and differing in phase with the main E.M.F. By means of a condenser placed in series in the circuit a phase displacement of E.M.F. may also be obtained. "Whenever E.M.F's displaced inphase are produced in this way,the currents are in phase with each other or are insignificant. Inversily., difference of phase of current can be produced in the single-phase current." If two coils are wound on an iron core and connected in parallel as shown in Fig. 1 the two currents in these coils (A and B) can be made to have any phase difference from zero to 180 by changing the relative number of turns, but the E.M.F's are still in phase. "Phase displacement of E.M.F. cannot

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[1] "Alternating Current System. C.P.Steinmetz, American Institute of Electrical Engineers, vol. 12, p. 332, 1895.

PLATE I.

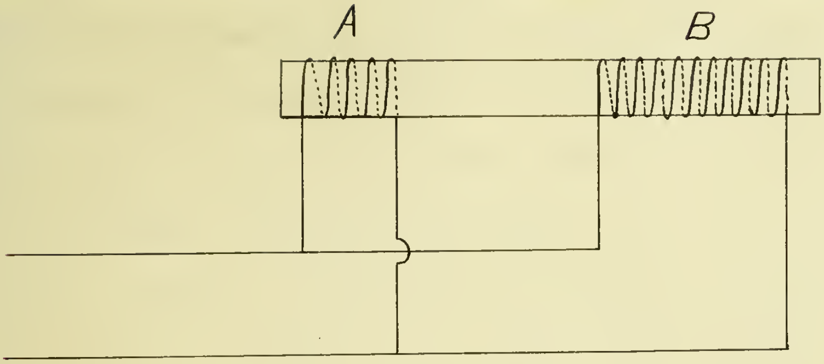

FIG. 1

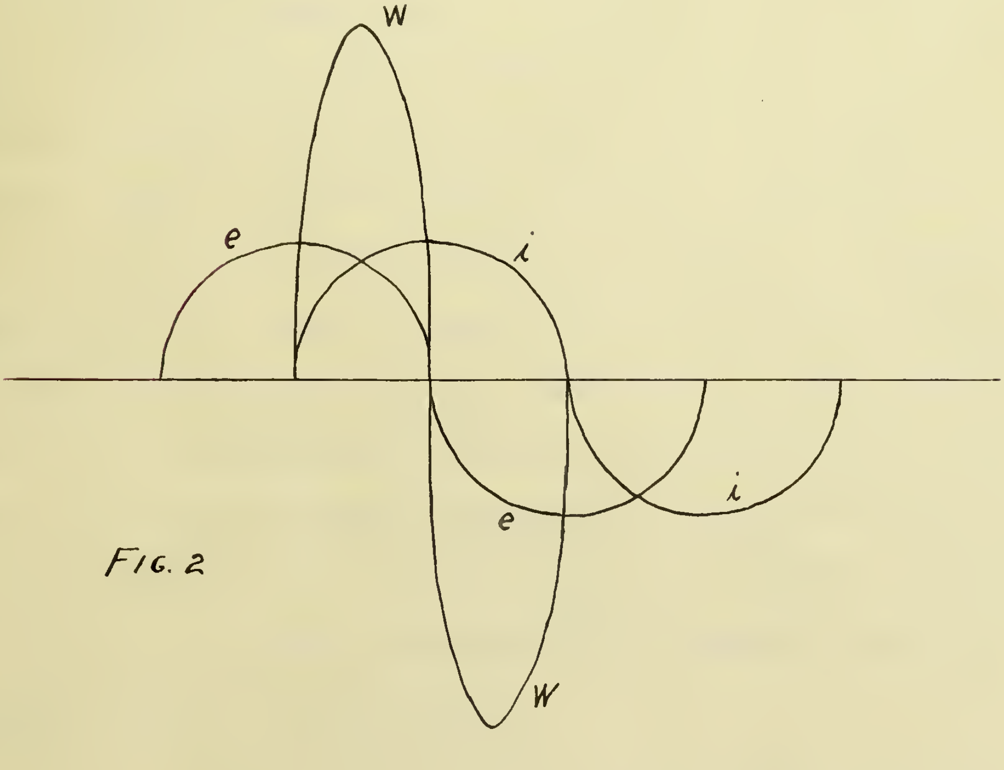

FIG. 2

be produced simultaneously in a single phase circuit. This is a consequence of the law of conservation of energy."

In a single-phase alternating current circuit the E.M.F. passes through zero twice per period. The current also alternates passing through zero at the same time with the E.M.F. if they are in phase as is the case in a non-inductive circuit, or at a different moment if not in phase. The power in the alternating circuit fluctuates between a maximum value and zero in the non-inductive circuit and between a maximum value and a negative maximum value in a circuit with phase displacement between current and E.M.F. In the latter case the power curve passes twice through zero per half wave. This is evident from an examination of Fig. 2 in which (e) represents E.M.F.,(i)the current and W the product of current and E.M.F.

In a three-phase system with three E.M.F's. producing three currents, the energy wave of each phase fluctuates as in the single-phase system. However, the sum of all the energy waves is constant. Thus it follows, from the law of conservation of energy that a change from single-phase to polyphase or inversely is possible only by means of apparatus able to store energy, and that the total amount of energy between the mean and maximum value in the single-phase circuit must be stored and returnned during the time the single-phase wave is below the mean. This is the principle upon which Mr. Charles S. Bradley constructed his one to three-phase transformer[2] Mr. Bradley's method will be considered more in detail later.

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2. "Phasing Transformers". Chas. S. Bradley. American Institute of Electrical Engineers. vol. 12, p. 505, 1895.

From what has been said it is clear that,by dividing a single-phase circuit into two branches and introducing an inductance in one branch and capacity in the other,a two-phase--three-phase or any desired polyphase currents may be obtained. It is an easy matter to transform from polyphase to two-phase or single-phase currents. It is in the reverse operation that difficulties present themselves.

The theory of the phase-relations[3] in a rotary transformer is comparatively simple. " The induced electromotive force in any one portion of the armature winding stands in the same phase-relation to that in any other portion as their angular separation on the ring." This refers to two pole machines. In case of multipolar machines it must be remembered that the pitch of the poles is equal to 180 electrical degrees. To produce a polyphase winding for any number of phases the armature or rotor is divided into the same number of symmetrical portions as there are phases and a slip ring connected to each point of division. The angular displacement between the different phases in all cases is the quotient of the circumference(degrees) by the number of phases. In all rotary transformers a rotating magnetic field is set up due to the interactions of the current in the stator and rotor,otherwise expressed as primary and secondary windings. By means of the resultant rotating magnetic field we are able to transform from polyphase to single-phase and vice versa.

5. Armature Inductance and Reactions in Rotary Phase-Transformers.-- In a synchronous converter used as a single or poly-

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[3] "Rotary Transformers". Geo.W.Colles.Journal Franklin Institute. vol.151,p.280,April 1901.

phase transformer the armature inductance and reactions depend upon the conditions of transformation. The reactions resulting from phase transformation on the slip-ring side alone are not so great as when single-phase is applied at the commutator end and three phase taken from the slip rings.

There is a small armature reaction in the rotary phase converter[4] due to the current driving the machine as a synchronous motor; also a slight reaction due to the wattless component of the alternating current. It is evident that the armature reaction and inductance will be less in a single coil than in a two coil armature.

"In converting to or from a single-phase current there is a periodic fluctuation of the magnetic field and if there is a lag in the single-phase current, there will be periodic strengthening or weakening of the field depending on whether the single-phase current is input or output. The armature reaction is the resultant of the generator reaction and the motor reaction and as they are opposite in effect and since the reaction of the polyphase current is very nearly steady, while that due to the single-phase is fluctuating and opposite to the former, the resultant will be fluctuating. In converting from one polyphase current to another polyphase current the resultant reaction is very small unless there is a lag or lead in one of the phases greater than in the other. With unity power factor in the input and a lag in the

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[4] "Armature Reaction in a Rotary Converter." discussion by C.P. Steinmetz. American Institute of Electrical Engineers. vol. 14, p. 478. 1897.

"The Rotary Phase Converter. Prof. R.W. Quick. Electrical World Engineer. vol. 6 1900.

output current,the resultant reaction will be demagnetizing, while if the reverse is the case,the resultant will cause increase in the field magnetism."

The effect of the armature reaction may be controlled by changing the field excitation;increasing the field excitation causing leading currents and decreasing it producing lagging currents in the output.

" The E.M.F. between consecutive leads of the output bear a fixed ratio,in any kind of transformation,to that between the leads of the input. In converting from single-phase to three-phase,100volts impressed on the single-phase side gives 86 volts on the three-phase side,assuming a sine distribution of magnetism."

" In the two-phase system opposite leads form one of the phases and since the E.M.F. of this system is that between these two leads,the ratio of pressure in converting two-phase to three-phase is the same as that for single-phase--three-phase conversion. For the same reason,in the single-phase--two-phase conversion,the ratio of E.M.F's.is unity."

In the asynchronous type of phase converter there is a difference in speed between the rotor and the rotating magnetic field. This difference is known as the slip of the machine,being proportional to the current flowing in the rotor winding and the resultant magnetic flux due to the inductance and reaction which take place between the primary or stator windings and the secondary or rotor windings.

CHAPTER III.

CLASSIFICATION OF PHASE TRANSFORMERS.

6. General.-- All phase transformers are included in the classes[5] of electrical apparatus,namely:(1) synchronous commutaling machines or converters,(2) stationary induction apparatus, (3) rotary induction apparatus. These three classes shall be taken up in the order named.

7. Synchronous Commutaling Machines or Converters.-- Synchronous commutaling machines include:(1)synchronous converters and (2)double current generators. " A converter is a rotary devise for transforming electric energy from one form into another without passing it through an intermediary form of energy. Phase converters are converters from an alternating current to an alternating system of the same frequency but different phase." It is with the synchronous converter as a phase converter that the author treats especially in the study of phase transformation. We may have also a synchronous commutating machine which is both a double current generator and a synchronous converter.

8. Stationary Induction Apparatus.is apparatus changing

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[5] Report of American Institute of Electrical Engineers,committee on the Standardization of Electric Generators. Motors and Transformers. June 26,1899.

electric energy from one form into another,without passing it through an intermediary form of energy. This includes stationary transformers in which the primary and secondary windings are electrically insulated from each other. Under transformers of this class we have static phase transformers,or transformers converting polyphase to single-phase or single-phase to polyphase currents. Some of the types of the static phase transformers will be considered briefly.

(a) The polyphase to single-phase is the simplest conceivable type of phase transformer. Some examples of this type are shown in Figs.3,4,5, and 6. Figs.3,5,and 6 represent three to one phase transformation,and Fig.4,two-phase to single-phase. In the three-phase transformation the three-phase--three wire system may be used instead of the six-wire system. In Figs. 3 and 4,a simple straight soft iron core is used. In Fig.5 we have a sogt iron ring while the core in Fig.6 is built of soft thin sheet-steel plates.

In the system of transformation shown in Fig.5 it has been the practice in this country to employ two separate transformers[6] with their primaries connected across two sides,respectively,of the three-phase system and with the mains connected in a similar manner to the respective secondaries. " In a patent issued May 12,1901 to Mr.E.W.Rice Jr. it is stated that a considerable economy in iron may be secured by locating the primary and secondary coils on a single core of such a nature that the flux due to the

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[6] "Polyphase Transformers.Electrical World and Engineer.vol.37 p.483.March 23,1901.

PLATE II.

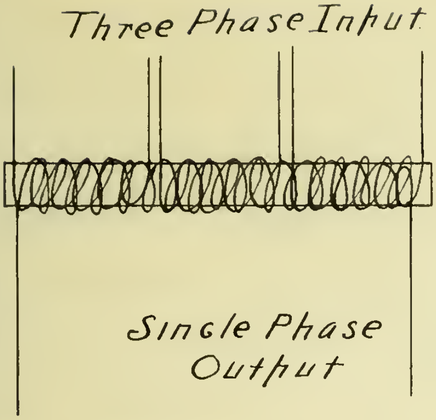

FIG. 3

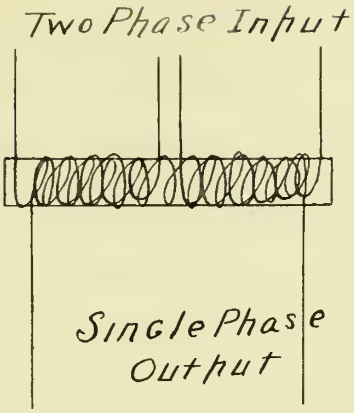

FIG. 4

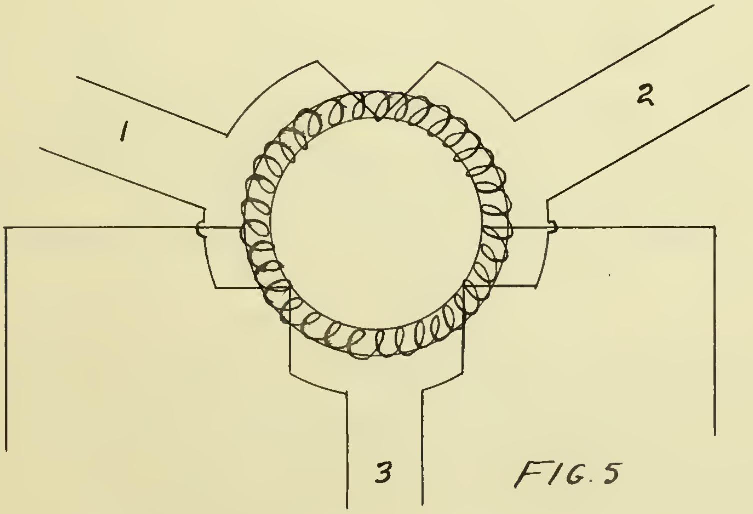

FIG. 5

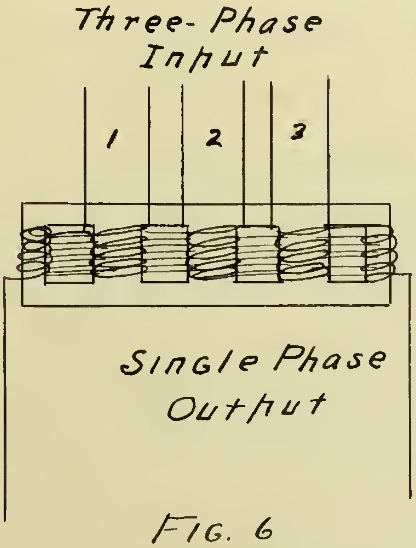

FIG. 6

action of one primary and its corresponding secondary may pass through a part of the iron core common to the magnetic circuit of the other primary and its secondary." The resultant flux passing that part of the iron core common to both magnetic circuits is the resultant of the two equal fluxes differing in phase from each other by an angle of 120 degrees. This resultant flux is equal in value to each of its component fluxes. This is apparent entfrom an examination of Fig.7 in which A and B are the two component fluxes of R, the resultant flux. The transformer is made rectangular in shape with two rectangular perforations. Fig.8 shows the general plan of the core and connections. In this case we have a primary and a secondary wound on each limb of the core. The secondaries may be connected in series for one voltage and in parallel for a different voltage. To secure several different voltages, the secondaries may be further subdivided.

The primaries may also be connected as shown in Figs.9 and 10.

Another method of polyphase to single-phase transformation due to Mr.Ludwig Gutmann is illustrated by Fig.11. A, B, and C are the three-phase primary coils wound on separate limbs of the transformer core. The secondary of the single-phase circuit is wound over all of the threephase primaries.

(b) Single-Phase to Polyphase and vise versa.-- In 1895, Mr.Chas.S.Bradley brought out his ingenious method[7] of single to polyphase transformation. As explained in Art.4, chapter II, difficulties are met in a transformation of this character. The real problem is to obtain two-phase currents or E.M.F. from a

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7. "Phasing Transformers." Chas.S.Bradley. American Institute of Electrical Engineers. vol.12, p.505, 1895.

PLATE III.

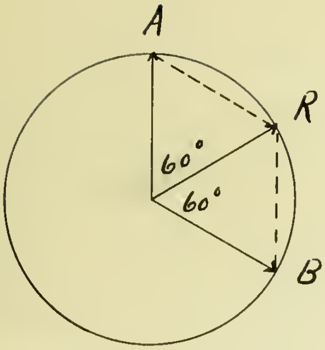

FIG. 7

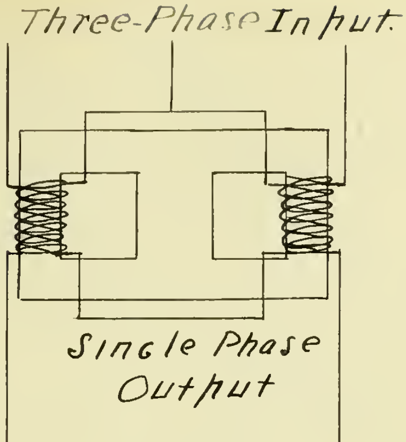

FIG. 8

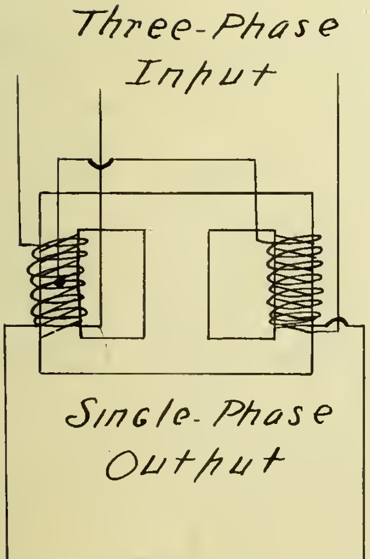

FIG. 9

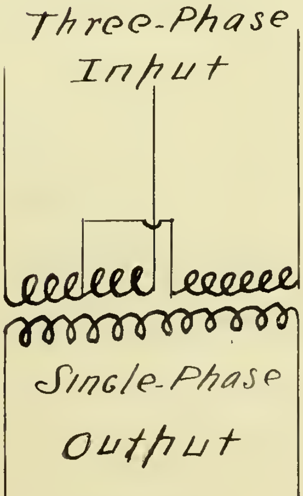

FIG. 10

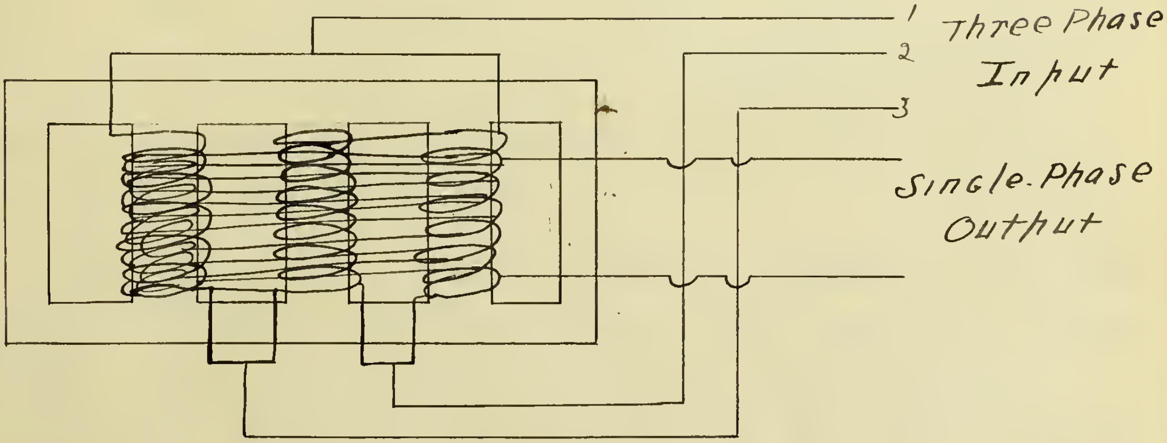

FIG. 11

single-phase circuit. After two-phase currents are obtained there is no difficulty in getting the three-phase. Fig.12 is a diagram of the method used by Mr.Bradley. A is a single-phase alternator,D a condenser and M a three-phase motor. The current from A goes through(r,)the primary of transformer S and then splits into two parts through(n)and(1), the primaries of transformer C. The part which goes through(n)goes to the condenser which is in series with(n) The capacity of this condenser is adjusted so that the magnetic flux in the core of transformer C differs approximately by 90 degrees in phase from that in S. This is done as follows: The current from(r)splits up into two parts,that in 1 lagging because of inductance and that in D leading because of capacity. Now if the current in(n)is taken in the reverse direction a current is obtained in the primary(nl)which lags 90 degrees with that in(r), hence two-phase currents result.

In order to get three-phase currents from the two transformers,various secondaries are wound on these transformers,shown as(g, h, i, j, k)in the figure. The coil(i)supplies one of the three alternating voltages. The coil(k)supplies an E.M.F. which is 90 degrees in advabce,which compounded with the E.M.F. og g, gives a total of 120 degrees in advance. Similarly the coil (j)which supplies an E.M.F. 90 degrees behind(i)is placed in series with the coil(h) which has just enough turns to make the total E.M.F. 120 degrees behind.

By using Mr, Chas.F. Scott's method of connecting secondaries and Mr. Bradley's primaries we have a much simplified transformation. Fig. 13 illustrates this method. Mr. Bradley's method will not give a true three-phase condition for all loads. It is necessary to readjust the inductance or capacity for different

PLATE IV

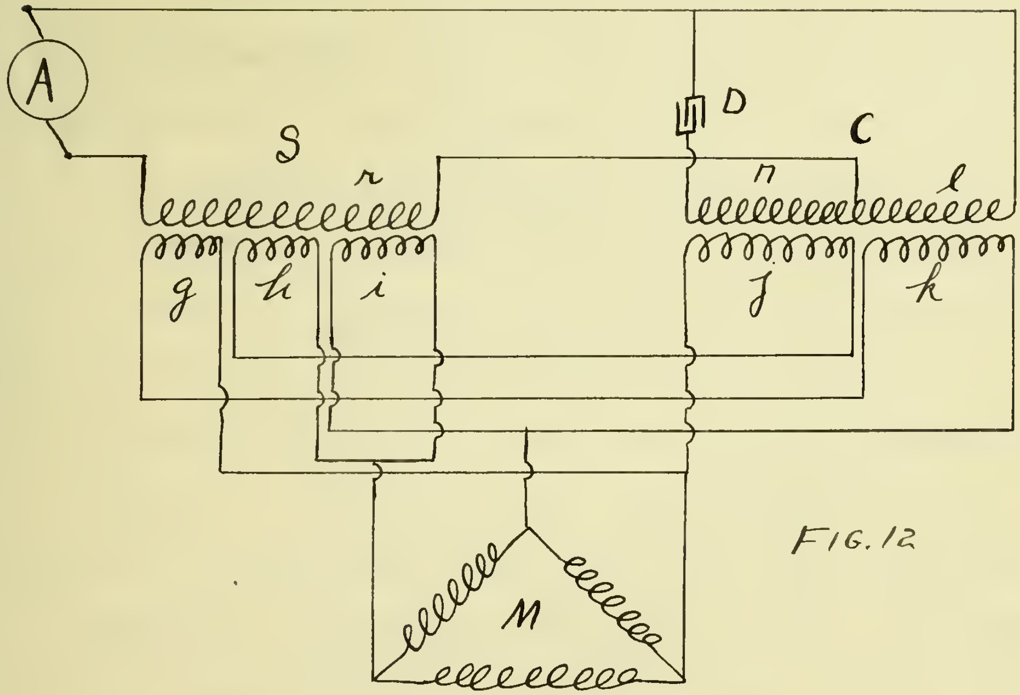

FIG. 12

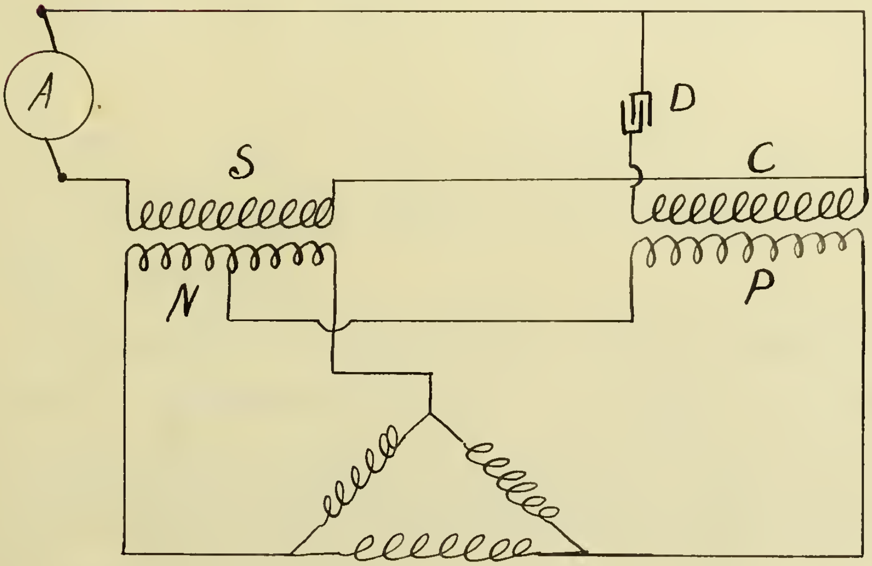

FIG. 13

loads to have a true three-phase circuit. This difficulty depends upon the nature of the load, whether inductive or non-inductive. Other methods for transforming from single to polyphase currents have been devised but the principles of all are the same. Mr. Bradley's method has not been proven to be successful commercially, the chief trouble being with the condenser.

(c) Two Phase to Three-Phase and vice versa.-- The first commercial system of two-phase--three-phase transformation was invented in 1894 by Mr. Chas. F. Scott[8] Chief Electrical Engineer for the Westinghouse Electric and Manufacturing Co.

This system is shown in Figs. 14 and 15, both representing the same thing in a different way. Fig. 16 shows the one arrangement of transformer cores and coils. The transformer consists of two cores with similar primaries A and B. These two primaries are connected to the two-phase mains. One core or limb of the transformer has a single secondary core, C, and the other has two similar secondaries each containing the same number of turns The secondary belonging to the primary B in Figs. 14 and 15 has $\frac{1}{2}\sqrt{3}$ times as many turns as the two combined secondaries of A.

The general practice in this country is to use a transformer in each leg as shown in Figs. 14 and 15. Fig. 16 represents the European practice.

9. Rotary Induction Apparatus.-- Rotary induction apparatus includes all apparatus in which the primary and secondary windings rotate with respect to each other. Nearly all types of

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[8] "Polyphase Transmission." Electrical World. vol. 23, p. 358; London Electrician. vol. 32, p. 640.

PLATE V.

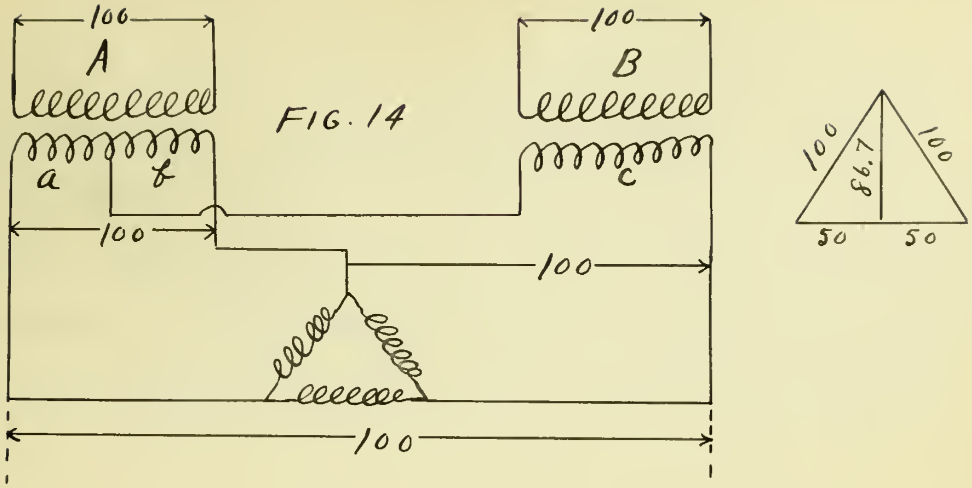

FIG. 14

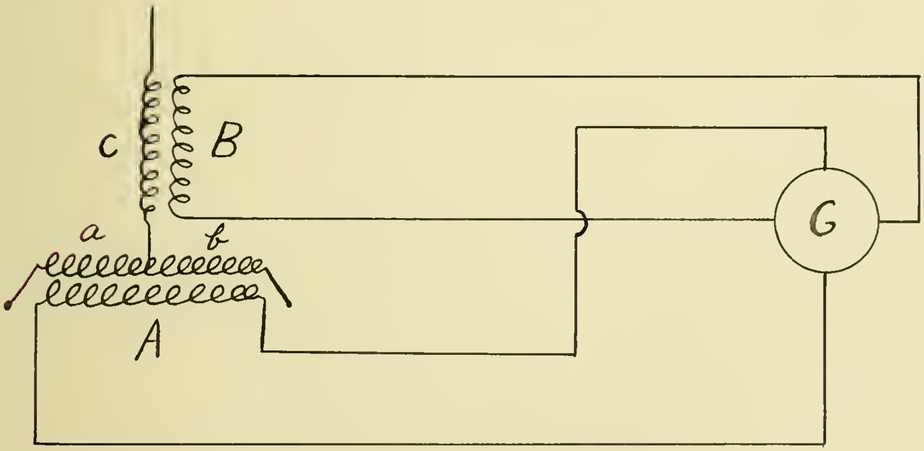

FIG. 15

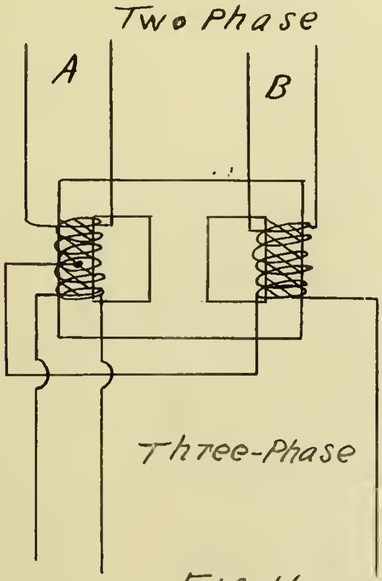

FIG. 16

rotary induction apparatus may be used as rotary phase converters with little or no change in their construction. By rotary phase converters we mean that type of rotary induction apparatus converting from an alternating system to another alternating system of different phase but of the same frequency. Included under rotary induction apparatus are also induction motors, induction generators and frequency changers, all of which may be used with little or no change as rotary phase transformers.

CHAPTER IV.

DESIGN OF PHASE TRANSFORMERS.

10. General.-- The design of phase transformers includes so many details in regard to constants, coefficients, electric and magnetic circuits, windings and mechanical and structual features that full justice could not be given this branch of the subject by the author. Suffice it to say that all of the details which enter into the design of transformers for other purposes than that a phase transformation must be included in the design of phase transformers. In fact these details form the greater part of the necessary data in phase transformer designs.

11. The selection of the type of phase transformer for a given service is first of all the most important feature of the design. In selecting the type to be used we must take into consideration the character of the load; character of the generator whether single phase or polyphase; length of transmission line; regulation of voltage and current; and the system of distribution. The most economical and substantial system should be installed and where phase transformation is necessary or can be economically used, phase transformers should be designed to fill the requirements of the case in hand.

For example, suppose a water power plant, generating single-phase or two-phase currents at a pressure of 500 volts, to be situated 10 miles from the centre of distribution. The voltage

is stepped up to 10000 volts at the generating station and transmitted, single-phase or two-phase, to the end of the line where it may, in the case of the two-phase transmission, be converted into three-phase and stepped down to 500 or 220 volts, as may be desired, by a Scott two to three-phase transformer.

In the case of a single-phase transmission the current may be stepped down to the required voltage by a separate static potential transformer and then converted to three-phase by a synchronous phase converter. In this latter case if direct current distribution is required the rotary can be operated as a synchronous single-phase motor, at the same time generating direct current at the commutator end. From this simple case it is evident that it is the service required that determine the type of phase transformer to be used.

CHAPTER V.

ECONOMY OF PHASE TRANSFORMATION.

12.-- As Related to Electric Transmission.-- In electric transmission, confining attention strictly to the line, the following points should be considered, namely; (a) the relative weights of copper required for the different systems and (b) the losses in the line due to ohmic and reactive drop, leakage, capacity and heating of conductors.

(a) Relative Weights of Copper[9].-- Generally speaking, a a saving in the total weight of copper needed for the transmission of a given amount of power to a given distance is effected by the use of the polyphase in preference to the single-phase system. The economy of copper-- which is the most important factor in the cost of long distance transmission-- depends upon the electric pressure at which the current is transmitted. Hence, in comparing different systems, the comparison should be made upon the basis of employing equal voltages although high voltage is a means of securing economy of copper in electric transmission. The voltage at which a system can be operated is determined by different considerations in different cases. When transformers are used, however, the voltage is determined by the consideration of the insulation which can safely be relied upon.

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[9] Polyphase Electric Currents. S.P.Thompson. page 62. Alternating Current Phenomena. C.P Steinmetz, p.473.1900. Standard Polyphase Apparatus and Systems. M.A.Oudin. p.214.1900.

The question arises, in comparing the advantages of various systems, whether we shall take as the basis of comparison the voltage between any two lines or the voltage between line and earth. If the maximum voltage between any point of the line and earth is taken as the basis of comparison, there is no saving in copper by the use of polyphase currents; for each line of any system, carrying a certain current at the maximum allowable voltage above the earth, may be considered as dependently transmitting a certain amount of power; and therefore the total power is simply proportional to the number of line wires, to which the total weight of copper is also proportional.

If, on the other hand, the maximum voltage between any two lines be taken as a basis of comparison, there is a decided economy of copper by the employment of three-phase currents. The single-phase system requires two wires, each of double cross section, as against the three wires of the three-phase system. Therefore, the weight of copper required on the three-phase system is only three-fourths of that required by the single-phase system. A two-phase four-wire system possesses the same economy of copper as the single-phase system.

If only three wires are used in the two-phase system, one wire acting as a common return, the voltage between the two outgoing lines is about 2 times the voltage between each line and the return; therefore we must regard the voltage of the system as 2 times the voltage between each line and the return. More copper is required in this case than for the single-phase transmission with equivalent voltage.

If a given power is to be transmitted at a given loss and a given maximum difference of potential in the system, the amount

of copper required is:

2 wires: Single-phase system	100.00
3 wires; Three-phase system	75.0
Two-phase system with common return	145.7
4 wires: Two-phase system	100.0

If a given power has to be transmitted at a given loss and a given minimum potential the amount of copper necessary is as follows:

2 wires: Single-phase system	100.00
3 wires: Single-phase system, neutral full section	37.50
" " " " " " half "	31.25
" " Inverted three-phase system	56.25
" " Two-phase system	72.90
" " Three-phase system	75.00
4 wires: Three-phase, neutral wire full section	33.30
" " " " " " half "	29.17
" " Two-phase system	100.00
5 " Single-phase system, full neutral	15.625
" " " " " half "	10.93
" " Four wire two-phase, common neu. full sec.	31.25
" " " " " " " " half "	28.125

It is evident from a study of the above table that, under the given conditions, the single-phase five wire system with half neutral is superior to any polyphase system. This system however is not a practical success on account of its complexity.

(b) Losses Due to Ohmic and Reactive Drop, Capacity and Leakage affect the choice of system to be installed and hence, indirectly, have a distinct bearing upon the subject of the econ-

omy of phase transformation. The most efficient system of transmission should be selected in any given case not only taking into consideration the relative weights of copper but also the various losses occurring under the given conditions. The choice of the most efficient system will depend upon the conditions to be met in individual cases. The simplicity or otherwise of construction, operation and control of the different systems of transmission will also affect their choice.

13. Alternating Current Regulation is another feature to be considered with regard to the relative economy of the different systems of phase transformation. Under the varying conditions of practical operation better voltage regulation will in general result from the selection of that system of transmission or distribution which most completely meets all of the requirements of the given service. However, if the best system as regards transmission, distribution and efficiency is selected, regulation may be considered as of minor importance in view of the successful regulating devices employed in modern installations.

14. The Value of the Polyphase Network in the distribution of alternating-current electrical energy is dependent to a great extent upon the economical operation of phase transformers. The relative economy of the different systems regarding the weight of copper used in transmission is discussed at the beginning of this chapter. The same rules apply to the subsequent distribution of electric energy. It has been demonstrated in practice and in theory that the polyphase system of distribution is the most efficient and economical system in nearly all cases. The polyphase network is more efficient and economical in

crowded localities, as in downtown districts, than where the distribution is over extended and thinly settled areas. Aside from the economic value of such a network in distribution is the reliability of service. One branch of the distributing network may, from any cause become inoperative, but this will not affect the operation of the other branches.

15. The Utilization of Alternating-Current Electrical Energy is a further important factor in determining the question of phase transformation. The nature of the receivers or power absorber usually decide the system employed in utilizing electric energy. By the use of phase transformers any system of supply as generated, whether single or polyphase, may, after transmission be converted into any other system to suit the requirements of the case.

CHAPTER VI.

CONSTRUCTION OF PHASE TRANSFORMERS.

16. General.-- Much may be written respecting the construction of phase transformers, especially in regard to electrical, magnetic, mechanical and structural details. The author has not attempted in this thesis to cover the whole field. Some of the most important features of construction of the two principal classes of phase transformers, stationary and rotary, are herein described. Also further description of the particular types used for the thesis experimental work is given.

17. Stationary Induction Phase Transformers are constructed in general similar to the common potential or current transformers. In this country it is the practice to combine two or more single-phase transformers to get the desired phase transformation. For instance, in the Scott system, the secondaries of two single-phase transformers are connected in such a manner (explained in a previous chapter) as to give a three-phase output with or without voltage transformation.

In European practice the same object is accomplished by using simply one transformer with the required number of cores or limbs. A static phase transformer may be constructed both as a potential and a phase transformer, serving one or both functions as may be required. For detailed information respecting the construction of transformers the reader is referred to the works of J.A.Fleming, D.C.Jackson, Gisbert Kapp, Maurice

A.Oudin,and the trade bulletins and circulars of the several manufacturers.

18. Rotary Induction Phase Transformers differ from those of the static type in that the primary and secondary windings rotate with respect to each other and the air gap between the two windings is increased. The increased air gap calls for a greater magnetizing current and the armature or secondary inductance is increased on account of the amount of iron in the secondary circuit. As explained before the leads or circuits for the required number of phases are tapped off at regular required intervals on the periphery of the armature depending upon the number of poles. Any form of rotary induction apparatus,as for instance the induction motor,may be used as a phase transformer by proper slip ring connections to the rotor or secondary windings. For detailed construction of this type of apparatus the reader is referred to Polyphase Electric Currents, by S.P Thompson.

19. Synchronous Phase Transformers are included in the general class of synchronous commutating machines. This apparatus converts from an alternating current system to an alternating current system of the same frequency but different phase. Synchronous converters,which may be also used as double-current generators,are often used as phase transformers.

The author made tests upon a General Electric 7 1/2 kilowatt and a Westinghouse 10 kilowatt synchronous converter as a phase transformer. The essential difference between these two machine consists in the field winding,arrangement of slip-rings and the device used in the Westinghouse rotary to prevent "hunting " and pumping. The fields of the Westinghouse machine are com-

pound wound. On the General Electric machine, 3-phase slip-rings are No's 1, 3, and 5, 2-phase rings are No's. 1 and 4, and 2 and 6. On the Westinghouse rotary the 3-phase rings are 1, 5 and 6, 2-phase rings are 1 and 3, and 2 and 4. The rings in this case are numbered from the armature outward. Below are given some of the measurements of the two machines.

List of Items	General Electric Machine.	Westinghouse Machines.
Factory Number	19987	185751
Type	Polyphase Converters.	Polyphase Converters.
Class	4--7.5-- 1800	4--10-- 1800
Frequency	60	60
Normal Voltage	110	440
Resistance of Field	----	680 ohms.

The armatures of the two machines are iron-clad of the usual toothed construction for distributed winding the cores being built up of laminated steel. Only a single winding is used on the armature thus reducing the I^2R loss. Leads to the slip rings are "tapped off" at different points o the armature as shown in Figs.17 and 18, between armature and slip rings.

Heating is an important consideration in the construction of phase transformers. The late Prof.R.W.Quick made a detailed study of heating[10] using a synchronous phase converter for the various transformations with different connections from armature winding to slip-rings.

20. In Converting from Single-phase to three-phase with the leads connected as shown in Fig.19, the distribution of heat is illustrated by Fig.20. With the armature connections as

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[10] The Rotary Phase Converter. Prof.R.W.Quick.Electrical World and Engineer. vol 35,p Jan.6 1900.

PLATE VI.

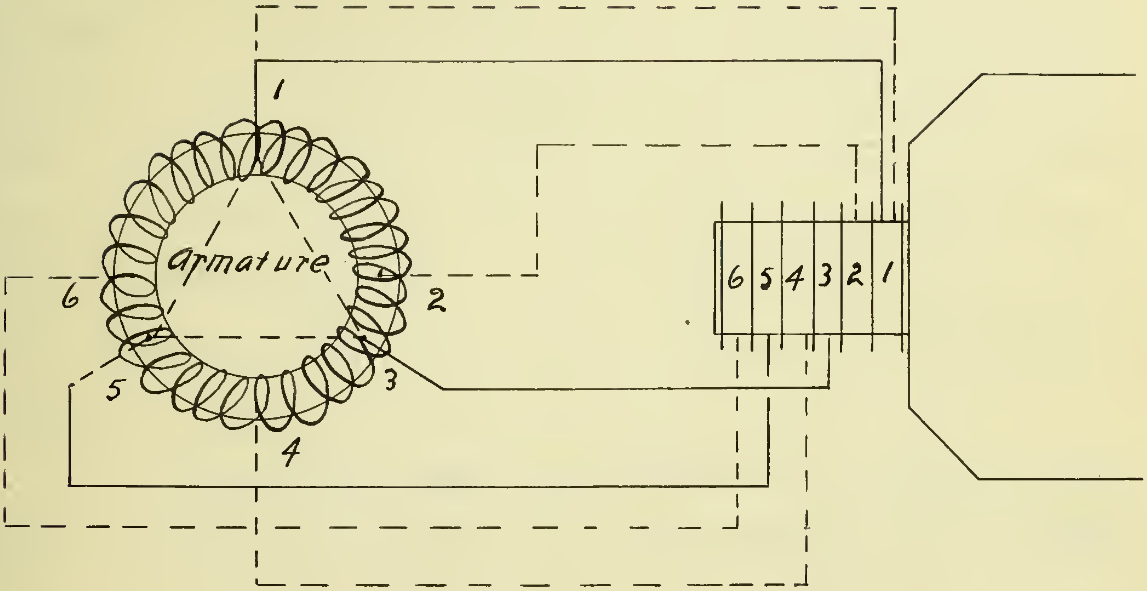

FIG. 17 GENERAL ELECTRIC Machine.

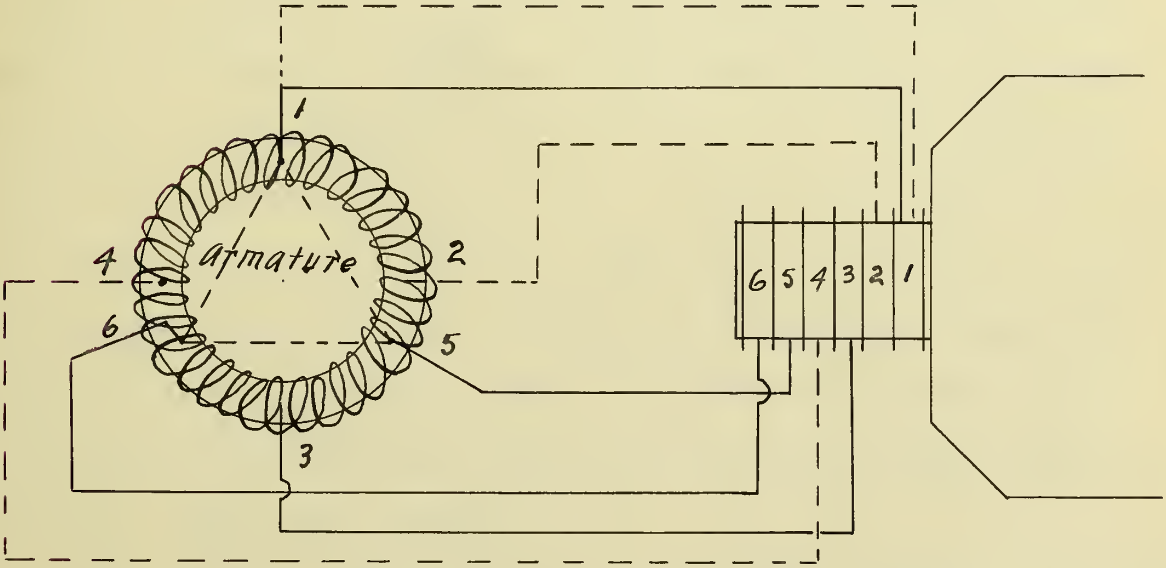

FIG. 18 WESTINGHOUSE Machine.

shown in Fig.21. he distribution of heat is illustrated by Fig. 22. In the former case, the angle α between lead (a_2) of the single-phase circuit and lead (a_3) of the three-phase circuit is zero. In the latter case, $\alpha = 30$ degrees. It is readily seen from an examination of the diagrams of heat distribution that the average production of heat when $\alpha =$ zero, is less than when $\alpha = 30$ degrees. The maximum rate of heat production in the former case is about six times the minimum rate. In the latter case, the maximum rate is forty-five times the minimum rate. It is therefore important in this kind of transformation that one of the single-phase leads should coincide with one of the three-phase leads, as shown in Fig.19, in which $\alpha = 0$

21. In Converting from Single-phase to Two-phase or vice versa the armature connections and heat distribution are shown respectively, in Figs. 23, 24, 25 and 26. When $\alpha = 0$ the single-phase leads coincide with two opposite leads of the two-phase system. This method of connection is more economical, giving perfect heat distribution.

22. In Two-phase--Three-phase Conversion, or vice versa, when $\alpha = 15$ degrees, the average heat production, H, in the armature, equals 0.584 I^2R, when I^2R is the maximum heat generated. When $\alpha = 0$ degrees, H = 0.527 I^2R. In converting from two to three-phase the generation of heat is less than in working as a direct-current generator and the relative position of the leads have little effect on the heat loss. The diagrams of connections and heat distribution for this case are shown respectively in Figs. 27, 28 and Figs. 29, 30.

23. Tables I. and II. show the calculated results that may be expected under various conditions of phase displacement.

PLATE VII.

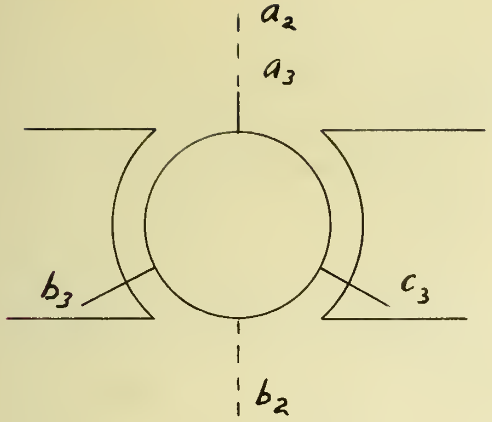

FIG. 19

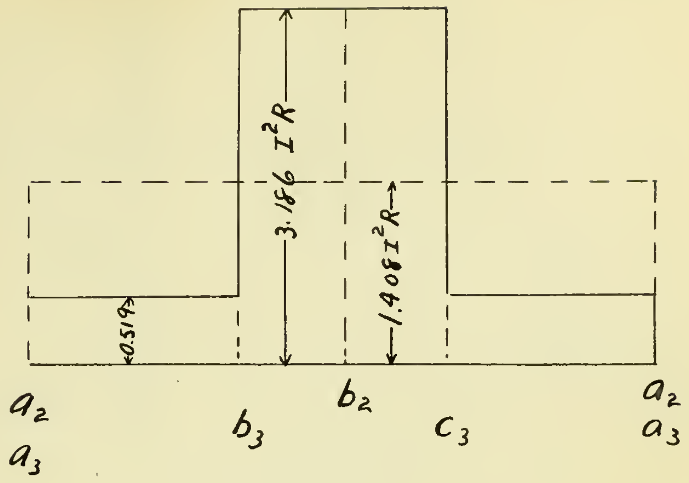

FIG. 20

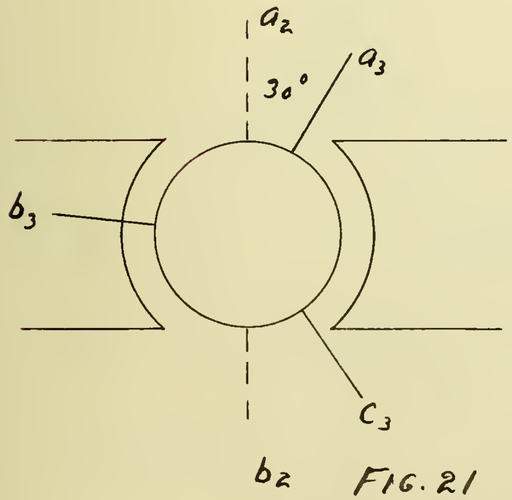

FIG. 21

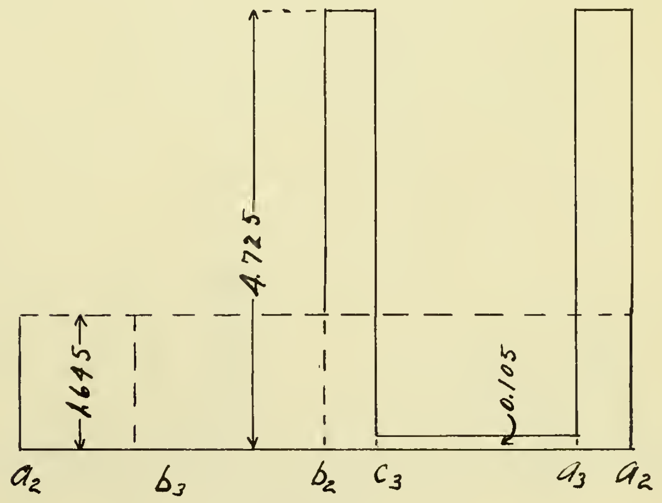

FIG. 22

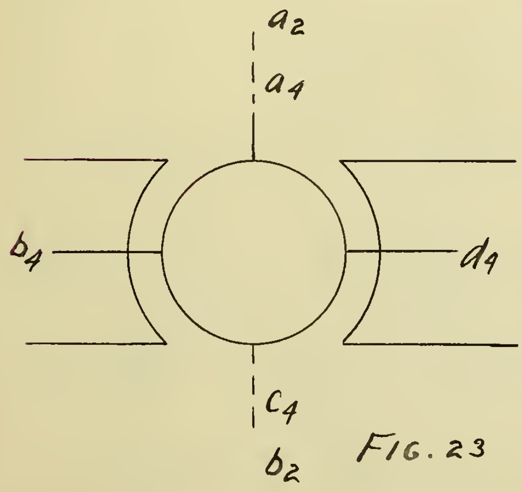

FIG. 23

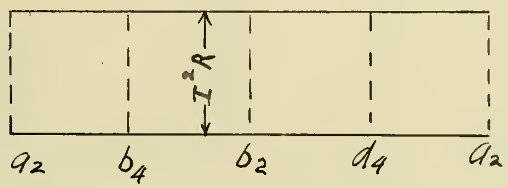

FIG. 24

PLATE VIII.

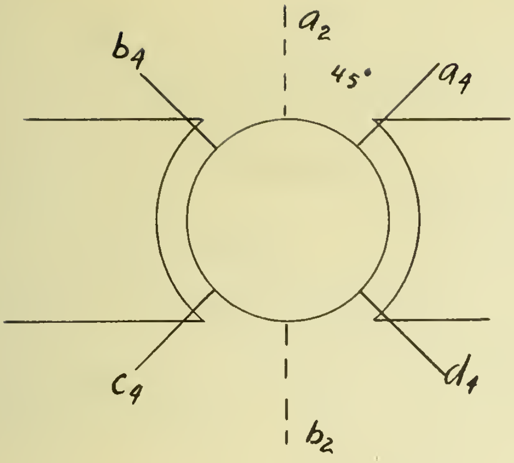

FIG. 25

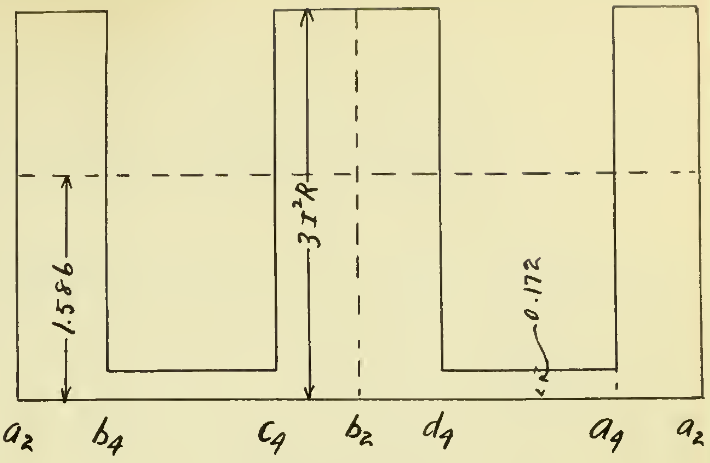

FIG. 26

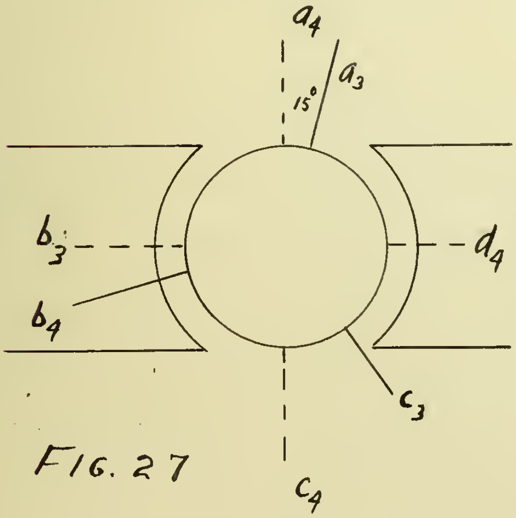

FIG. 27

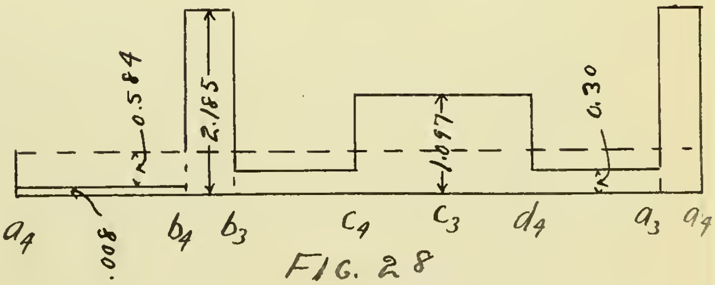

FIG. 28

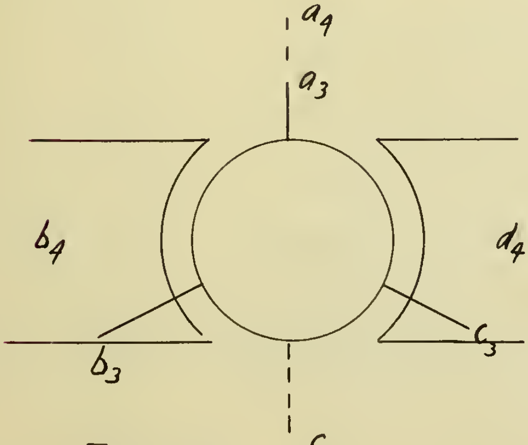

FIG. 29

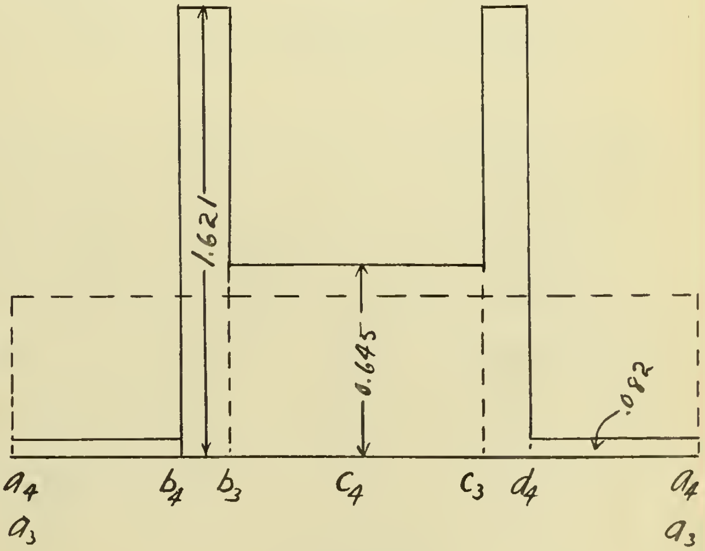

FIG. 30

TABLE I.

CALCULATED HEAT LOSS IN ROTARY PHASE TRANSFORMERS.

NO PHASE DISPLACEMENT IN EITHER EXTERNAL CIRCUIT.[11]

Conditions	Continuous Current	One to Three-phase		One to Two-phase		Three to Two-phase	
		α		α		α	
Maximum average loss	1	30°	1.645	45°	1.586	15°	0.584
Minimum average loss	1	0°	1.408	0°	1.00	0°	0.527
Maximum loss in a conductor	1	30°	4.725	45°	3.00	15°	2.185
	1	0°	3.185	0°	1.00	0°	1.621
Minimum loss in a conductor	1	30°	0.105	45°	0.172	15°	0.008
	1	0°	0.519	0°	1.00	0°	0.082

It is more economical to have one lead of one phase coincident with one lead of the other phase because the average rate of heat production is then less and the maximum heat loss in any conductor is therefore less. The heat loss, when there is no phase displacement in output or input is the same when transforming, as for instance, from two-phase to three-phase or vice versa but this is not true when there is a lag in the input current in each case.

From an examination of Tables I and II it is evident that for the least heating, whether there is any phase displacement in the input or output, one of the input leads should coincide with one of the output leads; that is, $\alpha = 0$."The percentage of

---

[11] Prof. R. W. Quick, Ibid.

TABLE II.

CALCULATED HEAT LOSS IN A ROTARY CONVERTER OPERATED AS A PHASE TRANSFORMER. PHASE DISPLACEMENT IN CIRCUITS.

Conditions.	One to Three-Phase	Three to One-Phase	One to Two Phase	Two to One-Phase	Two to Three-Phase	Three to Two-Phase.
Case I.	$\alpha = 30°$	$\alpha = 30°$	$\alpha = 45°$	$\alpha = 45°$	$\alpha = 15°$	$\alpha = 15°$
Phase Displacement	2.041	2.311	1.919	2.252	0.978	0.916
of Input Current = 0°	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$
of Output = 30° Lag.	1.803	2.074	1.333	1.666	0.922	0.860
Case II.	$\alpha = 30°$	$\alpha = 30°$	$\alpha = 45°$	$\alpha = 45°$	$\alpha = 15°$	$\alpha = 15°$
Phase Displacement	2.193	2.193	2.115	2.115	0.779	0.779
of Both Input and Out-	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$	$\alpha = 0°$
put Currents = 30° Lagging	1.877	1.877	1.333	1.333	1.333	0.703

increase in the heating due to a 30 degree lag in the output current is greater in the three to two-phase conversion, and vice versa, than in the one to three~~/~~phase conversion. it being 63 per cent in the former and 28 per cent in the latter case. With a given lag of 30 degrees in the output current, the heat loss is greater in converting from the greater number of phases to a less number, than the reverse; while it is the same in both cases when there is no lag."[12]

Since the ordinary details of construction of synchronous phase transformers do not differ from that of other direct and alternating generators the reader is referred to standard treatises on this subject.

Before leaving this branch of the work the writer wishes to call attention to some of the features of construction of a two-pole double-commutator machine, the armature of which was designed by Mr. Ludwig Guttman and constructed. in general, pursuant to the following specifications:

Art.24. INSULATION:- Standard insulation to be used on the core. No shellac should be applied to any part of the windings. The layers may be separated by a sheet of paper or oil paper, and the ends by cloth. the layers 2 and 5 may be separated by two sheets of paper or one of muslin.

SIZE OF WIRE should be #18 or #19 whichever will admit to place 6 or better 7 turns between the winding horns placed in the core. 7 turns are preferred.

If the first two layers can receive but 6 turns and owing to the larger diameter each section of layer 3 and 4 will admit the placing of 7 turns, then layers 1 and 2 shall receive 6 turns

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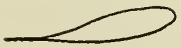
[12] Prof. F. W. Quick. Ibid.

per coil and layers 3 and 4, 7 turns per coil. Otherwise all 4 layers should receive all 6 turns or all 7 turns per coil.

COMMUTATORS:- There are to be placed two commutators on the shaft, one on each side of the core of 50 segments each. They should be so mounted on the shaft in the usual manner but placed so far apart, that if placed in the exciter frame and commutator bearing brackets applied on either side of the frame their position is correct with relation to the brush holders. If there is an end play please place small setting collars to prevent brushes from leaving the commutator.

ARMATURE WINDING:- There are to be wound 4 independent layers of wire on the core, two to be connected to commutator #1 on the left side and two to be connected to commutator #2 on their right side.

Each layer to form a complete armature in itself, but modified as described later on.-- There being 50 divisions on the core and 50 dividing horns, the space will admit of 25 complete coils placed on this first layer. The wire ends lying symmetrically all around the shaft. As there are but half as many coils as there are commutator segments the winding (after all other layers are in position) will be connected to alternate segments. The first layer is therefore connected to segments 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, 47, 49. This layer should form a complete and closed armature in itself, as if the intermediate commutator sections did not exist, and the armature was but a single layer winding with a commutator of 25 sections.- When winding, a loop  a FIG. 31 of 2-1/2 inches shall be brought out on five coils, on the opposite

end to the side of the commutator to which the winding is to be connected. These loops must be properly insulated to prevent a short circuit with the next layers. The five coils of layer #1 which are to have the loop are # 5, #10, #15, #20, and # 25 and the loop is made after half the coil is wound namely on the middle turn of the coil, (end of third turn if coil has six turns or middle of 4th turn if coil has 7 turns.) By this disposition we may obtain 5 loop a equidistant from one another 5 coils apart on the first layer. These loops may be painted black as also the ends of the wires that connect to segments 1 to 49 in uneven numbers. Then a second layer is wound, separated by a layer of paper from the first. The second layer will have also 25 coils which connect to the unoccupied commutator segments or even segments 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50. Here again 5 loops b are to be brought out at the same end of the armature but therefore displaced 3 sections from the loops already wound and are parts of (5- 3) coil 2 (10 - 3) coil 7, (15 - 3) coil 12, (20 - 3) coil 17 and(25 - 3) coil 22. After the two layers are wound there are a total of 50 coils using the whole left hand commutator and ten loops (5a X 5b) on the opposite end. The loops and wire ends of this second layer may be painted red to prevent a mistake in connecting it up. A pair of black wires should always alternate with a pair of red wires as they connect to the segments of the left hand commutator. Similarly the black and red loops should alternate and the red ones s should stand almost midway between the black.

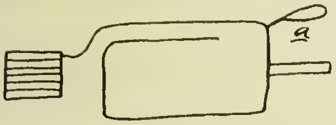


FIG. 32

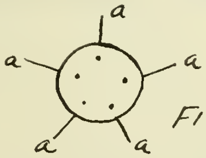


FIG. 33

This done double paper insulation or one of muslin is applied and two more layers put on top of the first two but while the winding still goes on in the same direction the beginnings of the coil are made to the right so as to connect the right hand or second commutator #2. Loops are also brought out as before not on the opposite side of the commutator but on the same side so that they come side by side of the first ten. The loops should be placed so that loops of layers #1 and #3 are together side by side and loops b and d of layers 2 and 4 are side by side. Loops of layer #3 are to be painted black as also the wire ends and the same parts of layer 4 are to be painted red. Then the black loops are connected together and the red loops are connected together. The insulation is removed for 1/4", the wires cleaned wound together with some fine copper binding wire and then soldered and carefully taped and insulated to avoid short circuits.-

We have 4 layers of armature windings constituting in reality 4 independent armature windings each of 25 coils.

Layer #1. 25 coils with 5 loops (black) (a) on middle turn of coils 5, 10, 15, and 25.

Layer #2. 25 coils 5 loops red (b) on middle turn of coils 2, 7, 12, 17, and 22.

Layer #3. 25 coils 5 loops (black) (c) on middle turn of coils 5, 10, 15, 20, and 25.

Layer #4. 25 coils 5 loops red (d) on middle turn of coils 2, 7, 12, 17 and 22.

Layers insulated from one another by paper, 2 and 3 by muslin loops a and c to be soldered also b and d always those that are next to each other and form pairs. The coil ends on both sides

to come out straight. The ends should however be left longer than necessary and bent down so that, they may be unsoldered and placed into other sections for giving them a lead. All wires are then tied down strong.bands should be placed on the windings on account of high speed of armature and the ends soldered into two commutators. If caps are placed the side containing the loop connections(the right side) should be marked so that one can know at a glance at which side they are located. If the windings causes the armature to be out of balance it should be properly balanced. Some mark should be applied whether cap is placed or not to know at once on which end the 20 loops are located.

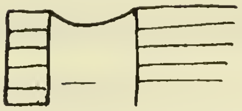


FIG. 34.

Solder onto the double loops a straight wire some 8"long which should be brought out insulated between the wires connected to the commutator.

Five or ten wires a brought outside the connecting wires going to the commutator and tied to the nearest wires going to the commutator in an insulated way, they are readily accessible, can be unwound.

The loops to be electrically connected should be joined by an 8" long wire of #14 or #15 B.& S. The one end should be used for connecting the two loops while the wire end remaining should be taped with insulating tape and brought out between the armature wires connected to the commutator and wrapped round the nearest wires and conveniently attached so as not to fly loose. for testing purposes.

25. Trial and Operation of the Double Commutator Machine .- There are two field coils each wound with 1560 turns of #19 B. & S. double cotton-covered wire. " With this winding 10 amperes

are obtained at from 100 to 120 volts. On a light load of about 5 amperes the voltage would remain at about 70,but at 10 amperes it would rise to about 200 volts"[13] The object of the loops";tapped off" at intervals of 72 degrees on each layer of winding, is to provide for ultimate connection to slip-rings. The intention was to supply a single-phase current to either commutator end,operating the machine as a single-phase synchronous motor and supplying any number of phases from the slip-rings as elsewhere described as the Gutmann Experiment. Also single-phase current can be applied to either end and direct current taken from the other end.

Case I. It was found by a number of experiments that this machine would not operate as a single-phase motor with or without field excitation,regardless of the magnitude of the input current. The armature would not rotate in either direction under any condition above described. Furthermore,the machine would not operate as a direct current motor or generator under any conditions experimented upon. The armature was tested throughout all its connections with a magnet,and also by current from a storage battery. By the magnet test all connections made with it rung up,when they should not have been heard from. When tested by a current from a storage battery the circuits were found to be interconnected as heretofore specified. The test of the armature winding served to show that it was somewhat"green" but no shellac was supposed to have been used in its construction.

Case 2. All the "loops" were finally unsoldered. The machine then operated very well as a direct-current motor. There

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[13] Builder's Specifications. Royal Electric Co.

was also manifest a tendency for the armature to rotate in a direction predetermined by the relative position of the brushes with respect to the bipolar field, when a single-phase current was supplied to one commutator end with no field excitation. The rotation was accompanied by a characteristic "growling" noise and excessive sparking at the brushes. The latter phenomenon is common in the Gut~~t~~mann Experiment before synchronous speed is reached. A single-phase current was supplied simultaneously to each end of the armature and the same effects were produced as just noted for single-phase current to one end. When the field coils were separately excited and connected first in parallel and later in series with each other, there was in each instance no tendency for the armature to rotate but it simply "stuck" in one position.

It seems obvious therefore, that the reason that the machine would not operate under any conditions in the first case, that is before the loops were cut, was due to opposed E.M.F's in the armature caused by a probable mistake in the interconnections of the loops described in the specifications. When the loop connections were cut as in case 2. the machine operated satisfactorily as a direct current motor and apparently had a tendency to operate after the manner described in the Gutmann Experiment.

CHAPTER VII.

OPERATION OF PHASE TRANSFORMERS.

26. The General Operating Conditions of any phase transformers are as follows:

1. One to two-phase and vice versa.
2. One to three-phase and vice versa.
3. Two to three-phase and vice versa.

In many instances, however, not all of these combinations can be made with any given transformer. A static transformer may be constructed to operate as a two to three-phase transformer and vice versa, but it cannot be used as one to three-phase transformer or vice versa.

27. The Relations of Operating Conditions to Phase Transformation is an important matter when the output conditions are considered for the various phase combinations and especially the effects of composite transmission. In phase transformation only, the voltage ratio of the transformer as such is practically unity although it may vary somewhat. In phase transformation the total power output might be expected to be practically the same as the input. But this is not realized in practice on account of the core loss and I^2R loss of static transformers with the addition of mecahnical loss in rotary phase transformers. Rotary phase transformers are constructed with devices for changing the voltage ratio and the frequency. A change in frequency affects the output of any phase transformer since the

core loss per cubic centimeter of iron depends upon the frequency. In the case of single to polyphase transformation the syetem is symmetrically loaded or balanced when the current is the same in each of the external polyphase circuits The system may be unbalanced by increasing or decreasing the load on only one circuit

In the operation of all types of phase transformers, phase converters, potential or current transformers heat effects must be carefuly guarded against by suitable dooling arrangements. Static transformers may be self-cooling, oil cooled, water and oil cooled. Temperatures may be kept down by means of an air blast. The method of cooling depends somewhat upon the capacity of the transgormer.

The effect of composite transmission[14] upon output relations for various phase combinations is an interesting field of study. Owing to the lack of time the author did not experimentally investigate this feature.

Art. 28.- A Synchronous Phase Transformer may be started as a direct-current motor, as an alternating current induction motor and from an independent source of power, mechanically or by another motor. Two of these methods of starting are entirely successful. The trouble in starting the motor transformer a an alternating current motor is in getting it up to synchronous speed. In one of the machines tested the normal speed was 1800 R.P.M. but in starting it as an alternating current induction motor there was some difficulty i obtaining this speed. A synchronous phase converter may be operated successfully for any of the

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14. Starting a Rotary by Direct Current Transmitted over the Alternating Line. Frederick Bedell. Sibley Journal of Engineering June, 1900.

phase combinations stated in Art.26. Usually the transformer is brought up to synchronous speed by starting it as a direct current motor and then synchronizing by means of incandescent lamps placed in the alternating-current circuit. In case of applying single-phase current to the commutator end of the transformer and supplying the desires phase from the slip-rings the transformer armature must be rotated independently. This latter operation is what is known as the "Gutmann Experiment " being suggested and tested by Mr.Ludwig Gutmann,of Peoria,Illinois.

The regulation of the relation between input and output energy may be controlled by inserted resistance,variation of field excitation when operated as a synchronous motor,and variation of speed when rotation of the armature is effected independently.

In operating the synchronous phase converter as a synchronous motor the frequency cannot be varied but remains constant. When the machine is operated independently the output may be varied by changing the frequency. " A variation of impressed E.M.F. causes a relative variation of output E.M.F's. The voltage may be regulated by resistance or a special potential regulator in connection with potential transformers."

29. An under excited synchronous phase converter has the same effect as an induction motor when operated on a lighting circuit. A low power factor then exists and the lamps "blink" when the converter is started. When over excited the machine produces the same effect as inserted and combined capacity and resistance somewhat equivalent to an electrolytic condenser, but in this case also the power factor may be low. The best operating condition is at unity power factor which may be secured

at almost any load desired by changing the excitation until the output wattmeters read the same.

30. The Ageing of Iron in static transformer cores is a question which has recently been investigated thoroughly. It is not, however, a question which should cause uneasiness on the part of the user of transformers, of any type, because of the extreme care of reliable manufacturers in securing the best possible material for the transformer cores, and subsequent heat treatment.

CHAPTER VIII.

PERFORMANCE AND TESTING OF PHASE TRANSFORMERS.

31. General.-- The method of testing phase transformers varies according to the type. In general the same considerations and evaluations must be taken into account in the performance and testing of all phase transformers. The writer has not gone into all of the details in regard to the performance and testing of the several different types but some of the features of the action of synchronous phase converters will be considered in particular.

32. The Performance and Testing of Synchronous Phase Transformers takes into consideration the following points:

1. Principles, methods; errors, precision of measurements.
2. Effect of variables on performance; voltage, frequency, excitation, character and amount of load, wave form, etc.
3. Voltage regulation and ratios.
4. Phase relations and characteristics.
5. Efficiency of, and losses of machine operated under various conditions.
6. Magnetic determinations; leakage, potential distribution, induction and magnetization.
7. Armature resistance, inductance and reactions.
8. Special features, results, deductions and conclusions.

Some of the above points above enumerated have been considered

PLATE IX

Westinghouse 10 K.W. Rotary Converter as a One to Two-Phase Transformer.

Experiment No. 1

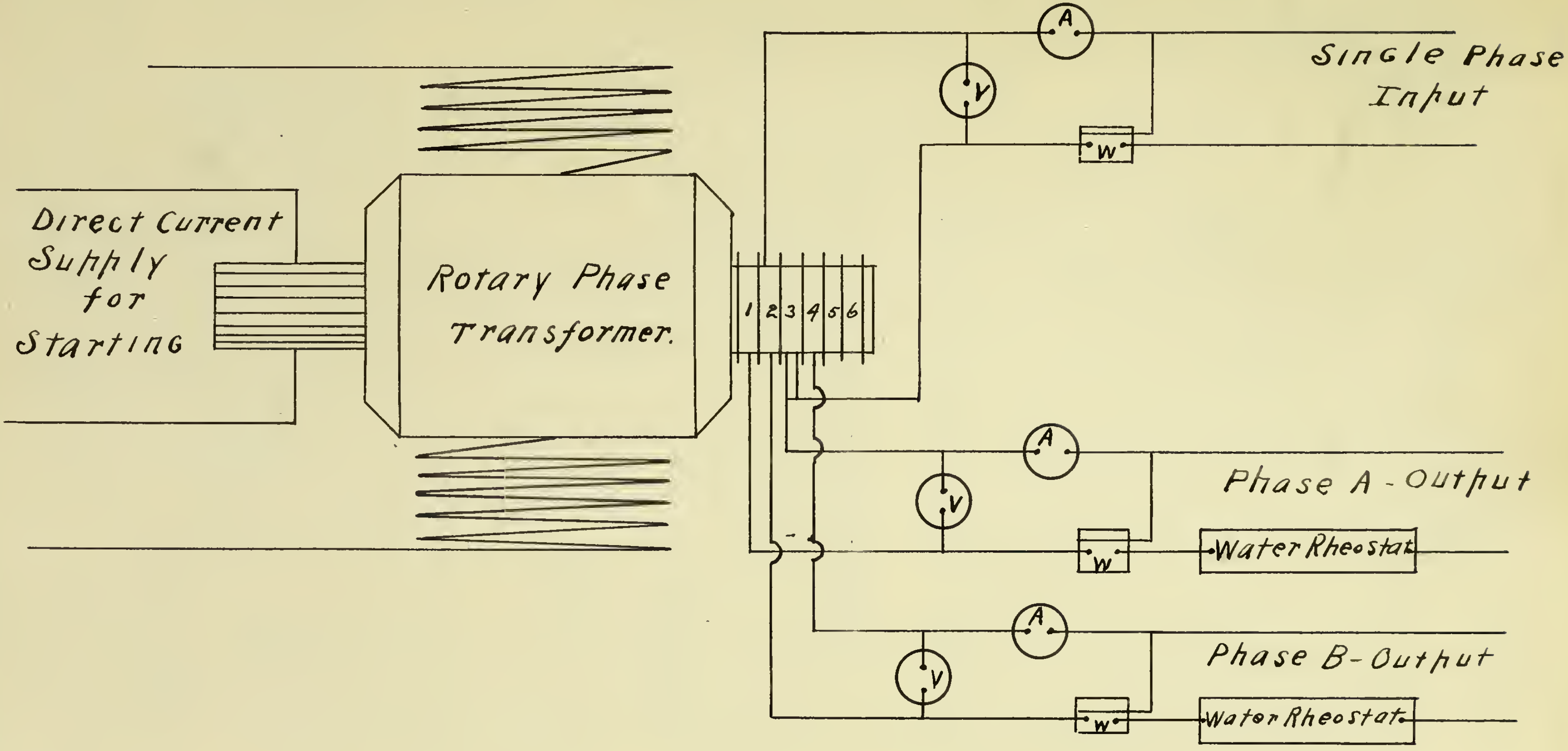


FIG. 35.

in previous articles, others will be taken up in the performance and test of the Westinghouse and General Electric rotary converters as given in the following experiments.

33. Experiment No.1.-- The Westinghouse 10 kilowatt rotary converter was operated as one to two-phase trans former, fields separately excited, under non-inductive load. This consisted of a water rheostat placed in each phase of the external circuit. The field resistance, (hot) measured 680 ohms. The machine was started as a direct-current motor, synchronized and operated as a single-phase motor generating two-phase from slip-rings one and three, two and four. The single-phase rings were one and three. A diagram of connections is shown in Fig. 35 Plate 9 ,page 47 .

34. Explanation and Discussion of Experiment No.1. Tables III., IV., and V. give respectively corrected observations, calculated results, and values to be platted. This is the order of tabulated data throughout this series of experiments. The following curves have also been platted:

Series of Platted Results for Experiment No.1.

Plate 10 , Watts lost, Excitation base.

Plate 11 , True and Apparent Efficiencies, True Watts Input Base.

Plate 12 , Input Power Factor, True Watts Input Base.

Plate 13 , True and Apparent Watts Input, Excitation Base.

Plate 14 , Amperes Input, Excitation Base.

Plate 15 , Voltage Ratios. Excitation Base.

Plate 16 , Leading and Lagging Power Factors Excitation Base.

The field loss was calculated from the resistance of the field and exciting current. Armature and friction losses were given by the observed input with no load output. The total

TABLE III. Experiment No. 1.

Corrected Observations. Westinghouse 10 K.W. One to Two-Phase Transformer. Non-inductive Load. Separately Excited. Constant Input.

Number	INPUT			OUPUT A			OUTPUT B			Exc.
	Weston	Thompson	Weston	Weston	Thompson	Weston	Weston	Thompson	Weston	Weston
	#2322	#14030	#213	#831	#13457	#1060	#857	#14010	#775	#9082
	Vm	Am	Wm	Vm	Am	Wm	Vm	Am	Wm	Am
	1	2	3	4	5	6	7	8	9	10
1	471	5.5	400	472	0	0	479	0	0	0.65
2	470	8.3	380	470	0	0	478	0	0	0.50
3	469	13.2	490	468	0	0	487	0	0	0.80
4	461	10.8	4000	460	3.0	1600	417	2.7	1040	0.50
5	461	9.3	4000	460	3.0	1680	437	2.1	800	0.60
6	461	10.5	4000	460	3.0	1720	451	1.9	840	0.65
7	461	12.0	4000	461	3.0	1760	461	1.5	760	0.70
8	457	16.8	4000	455	3.0	1800	481	0.9	400	0.80
9	457	14.3	6000	455	4.0	1840	407	6.3	2480	0.50
10	459	13.5	6000	455	4.0	1840	426	5.8	2600	0.60
11	457	14.3	6000	455	5.5	2200	441	4.91	2120	0.65
12	467	15.2	6000	466	5.3	2000	455	5.0	2200	0.70
13	471	17.6	6000	467	3.0	1800	476	4.52	2080	0.80
14	465	19.0	8000	466	6.0	2720	406	8.8	3600	0.50
15	467	17.8	8000	466	6.0	2400	426	9.1	3960	0.60
16	465	18.2	8000	466	7.0	3240	446	6.9	3000	0.65
17	464	19.3	8000	466	6.0	2960	451	7.2	3200	0.70
18	464	20.8	10000	465	13.6	6400	427	3.2	1200	0.50
19	468	19.8	10000	460	13.7	6400	437	3.1	1240	0.60
20	460	20.5	10000	460	14.5	6400	453	3.2	1520	0.65
21	460	21.3	10000	460	13.5	6200	465	3.5	1600	0.70

TABLE IV.

Calculated Results of Experiment No. 1.

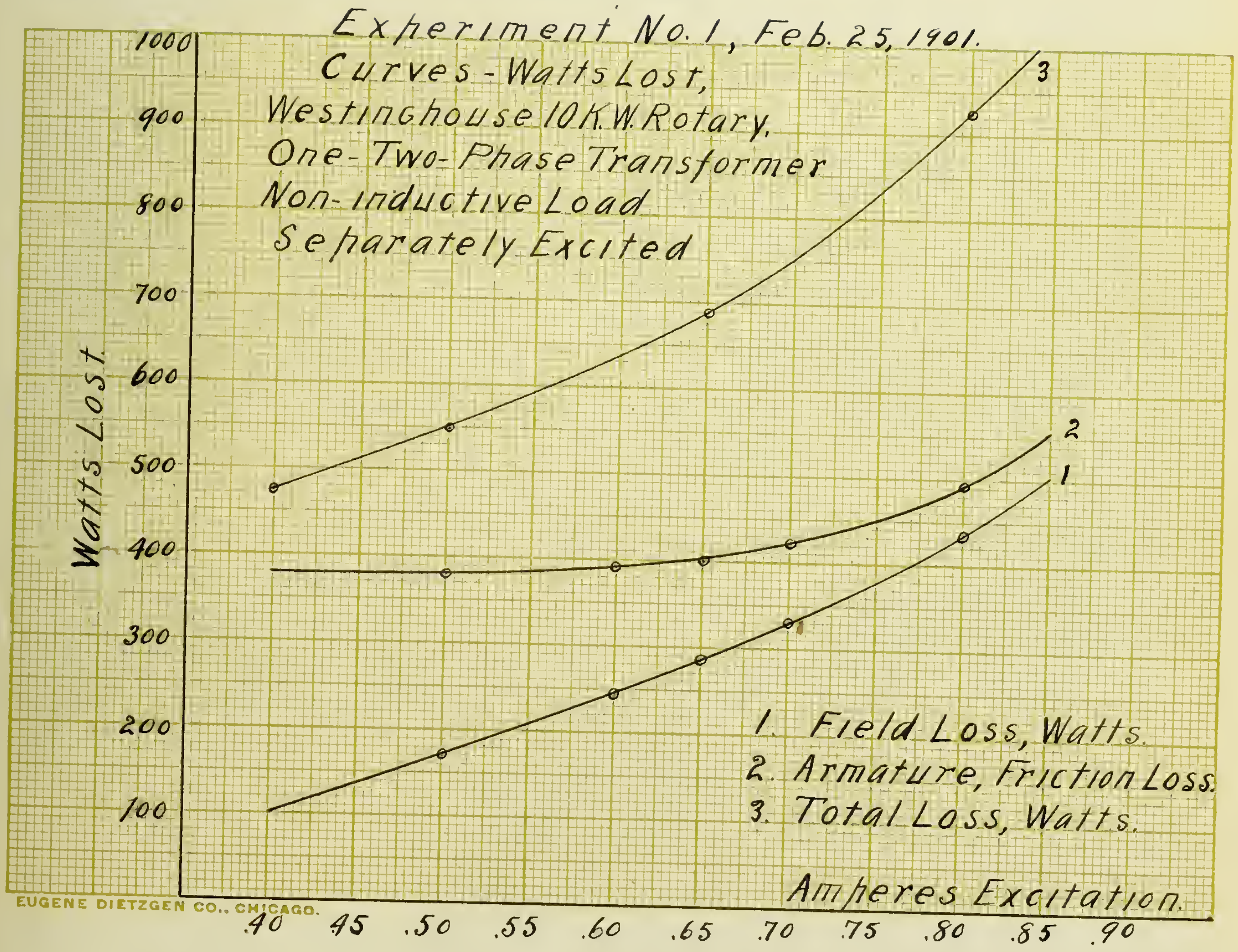
	1 Apparent Watts Input	2 Input Power Factor.	3 Watts Field Loss	4 Total Watts Input	5 Total Watts Output	6 True Efficiency	7 Apparent Efficiency	8 Volt Ratio Phase A	9 Volt Ratio Phase B
1	2580	0.155	287	687	0	0	0	1	1.02
2	3900	0.098	170	550	0	0	0	1	1.02
3	6140	0.080	435	925	0	0	0	1	1.04
4	4980	0.80	170	4170	2640	0.633	0.506	1	0.905
5	4280	0.93	245	4245	2480	0.585	0.545	1	0.948
6	4840	0.83	287	4287	2560	0.598	0.497	1	0.978
7	5532	0.72	333	4333	2520	0.582	0.42	1	1.00
8	7670	0.52	435	4435	2200	0.496	0.258	1	1.05
9	6530	0.92	170	6170	4320	0.70	0.644	1	0.89
10	6200	0.97	245	6245	4440	0.71	0.69	1	0.93
11	6530	0.92	287	6287	4320	0.687	0.632	1	0.965
12	7100	0.845	333	6333	4200	0.665	0.562	1	0.975
13	8300	0.725	435	6435	3880	0.605	0.44	1	1.02
14	8840	0.905	170	8170	6320	0.774	0.70	1	0.874
15	8300	0.964	245	8245	6360	0.773	0.745	1	0.913
16	8460	0.945	287	8287	6240	0.753	0.72	1	0.96
17	8950	0.895	333	8333	6160	0.74	0.662	1	0.972
18	—	—	170	10170	7600	0.747	—	1	0.92
19	—	—	245	10245	7640	0.745	—	1	0.935
20	—	—	287	10287	7920	0.765	—	1	0.985
21	—	—	333	10333	7800	0.757	—	1	1.02

TABLE V.

Values to be Platted for Experiment No. 1

	1	2	3	4	5	6	7	8	9	10	11	12
Number	Power Factor	True Efficiency	Apparent Efficiency	Volt Ratio Phase A	Volt Ratio Phase B	Watts Field Loss	Armature and Friction Loss	Total Watts Lost	Input Current	Input Watts	Total Watts Input	Field Excitation
1	0.155	0	0	1	1.02	287	400	687	5.5	400	687	0.65
2	0.098	0	0	1	1.02	170	380	550	8.3	380	550	0.50
3	0.080	0	0	1	1.04	435	490	925	13.2	490	925	0.80
4	0.80	0.633	0.506	1	0.905	170	—	—	10.8	4000	4170	0.50
5	0.93	0.585	0.545	1	0.948	245	—	—	9.3	4000	4245	0.60
6	0.83	0.598	0.497	1	0.978	287	—	—	10.5	4000	4287	0.65
7	0.72	0.582	0.42	1	1.00	333	—	—	12.0	4000	4333	0.70
8	0.52	0.496	0.258	1	1.05	435	—	—	16.8	4000	4435	0.80
9	0.92	0.70	0.644	1	0.89	170	—	—	14.3	6000	6170	0.50
10	0.97	0.71	0.69	1	0.93	245	—	—	13.5	6000	6245	0.60
11	0.92	0.687	0.632	1	0.965	287	—	—	14.3	6000	6287	0.65
12	0.845	0.665	0.562	1	0.975	333	—	—	15.2	6000	6333	0.70
13	0.725	0.605	0.44	1	1.02	435	—	—	17.6	6000	6435	0.80
14	0.905	0.774	0.70	1	0.874	170	—	—	19.0	8000	8170	0.50
15	0.964	0.773	0.745	1	0.913	245	—	—	17.8	8000	8245	0.60
16	0.945	0.753	0.72	1	0.96	287	—	—	18.2	8000	8287	0.65
17	0.895	0.74	0.662	1	0.972	333	—	—	19.3	8000	8333	0.70
18	—	0.747	—	1	0.92	170	—	—	20.8	10000	10170	0.50
19	—	0.745	—	1	0.935	245	—	—	19.8	10000	10245	0.60
20	—	0.765	—	1	0.985	287	—	—	20.5	10000	10287	0.65
21	—	0.757	—	1	1.02	333	—	—	21.3	10000	10333	0.70

Plate X.



Experiment No. 1, Feb. 25, 1901.
Curves - Watts Lost,
Westinghouse 10 K.W. Rotary,
One-Two-Phase Transformer
Non-inductive Load
Separately Excited

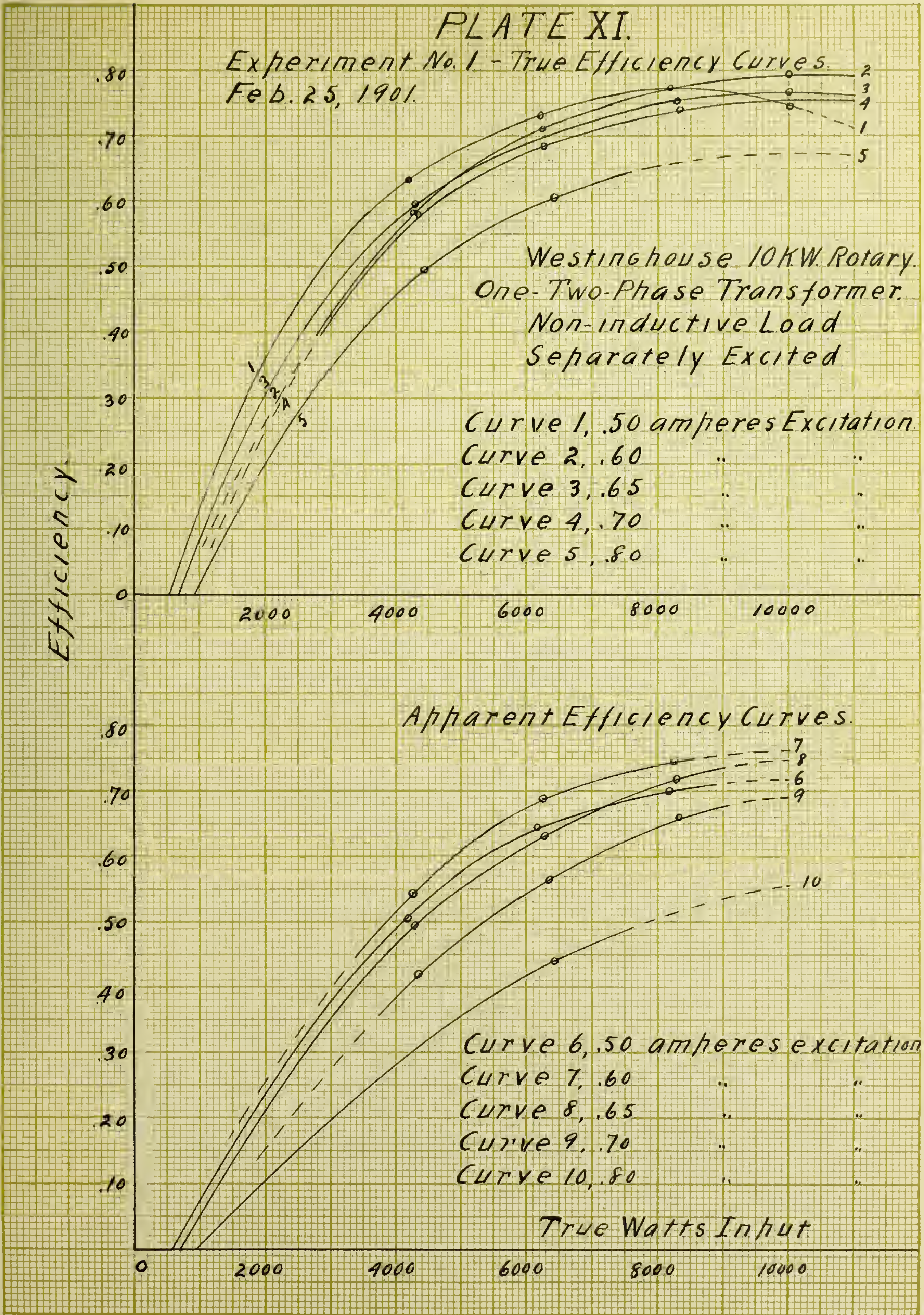


PLATE XI.

Experiment No. 1 - True Efficiency Curves.
Feb. 25, 1901.

Westinghouse 10 K.W. Rotary.
One-Two-Phase Transformer.
Non-inductive Load
Separately Excited

Curve 1, .50 amperes Excitation.
Curve 2, .60 " "
Curve 3, .65 " "
Curve 4, .70 " "
Curve 5, .80 " "

Apparent Efficiency Curves.

Curve 6, .50 amperes excitation
Curve 7, .60 " "
Curve 8, .65 " "
Curve 9, .70 " "
Curve 10, .80 " "

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PLATE XII.

Experimet No. 1 Feb. 25, 1901.
Power Factor Curves.
Westinghouse 10 K.W. Rotary
One-Two-Phase Transformer.
Non-inductive Load
Separately Excited

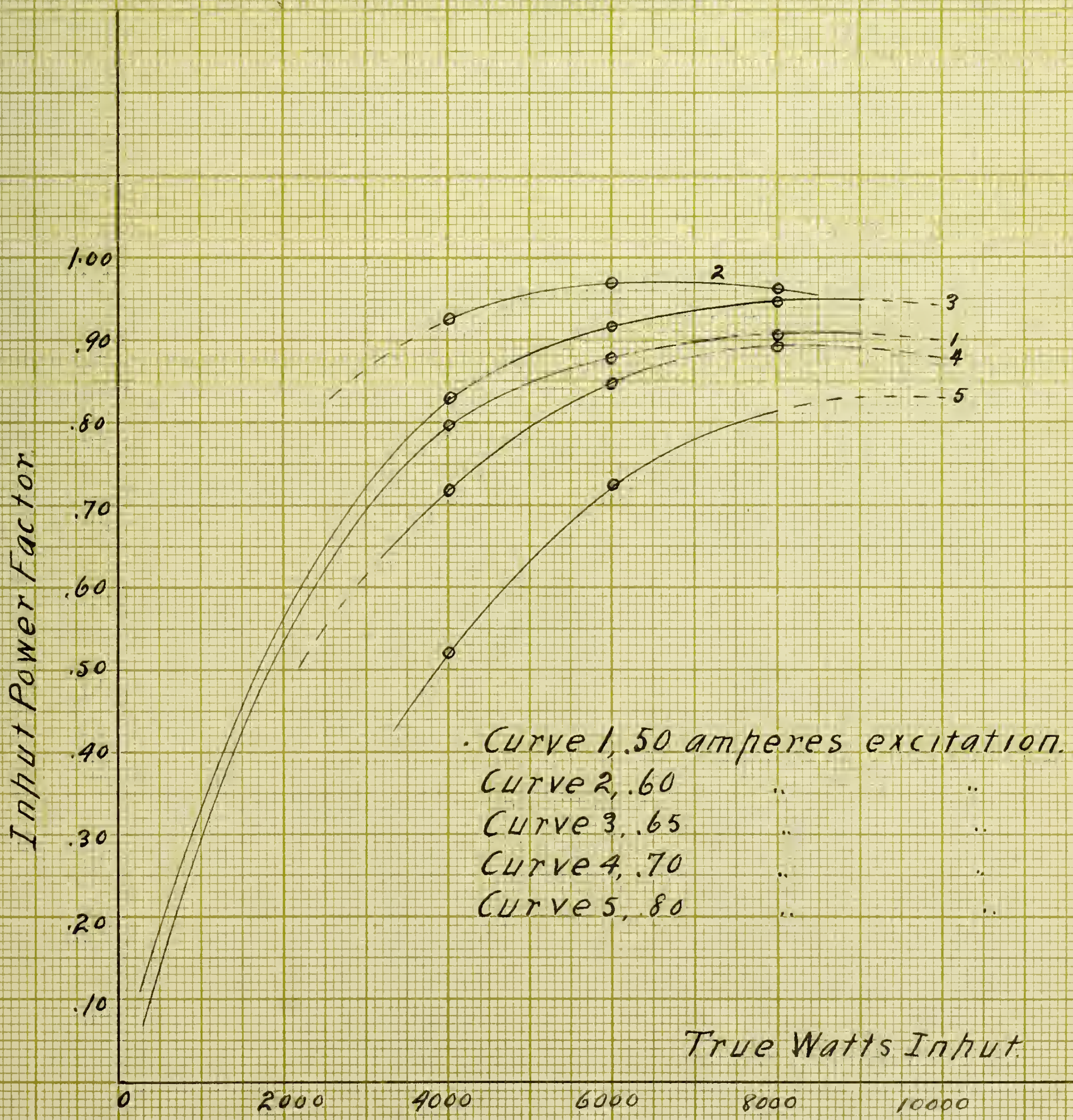

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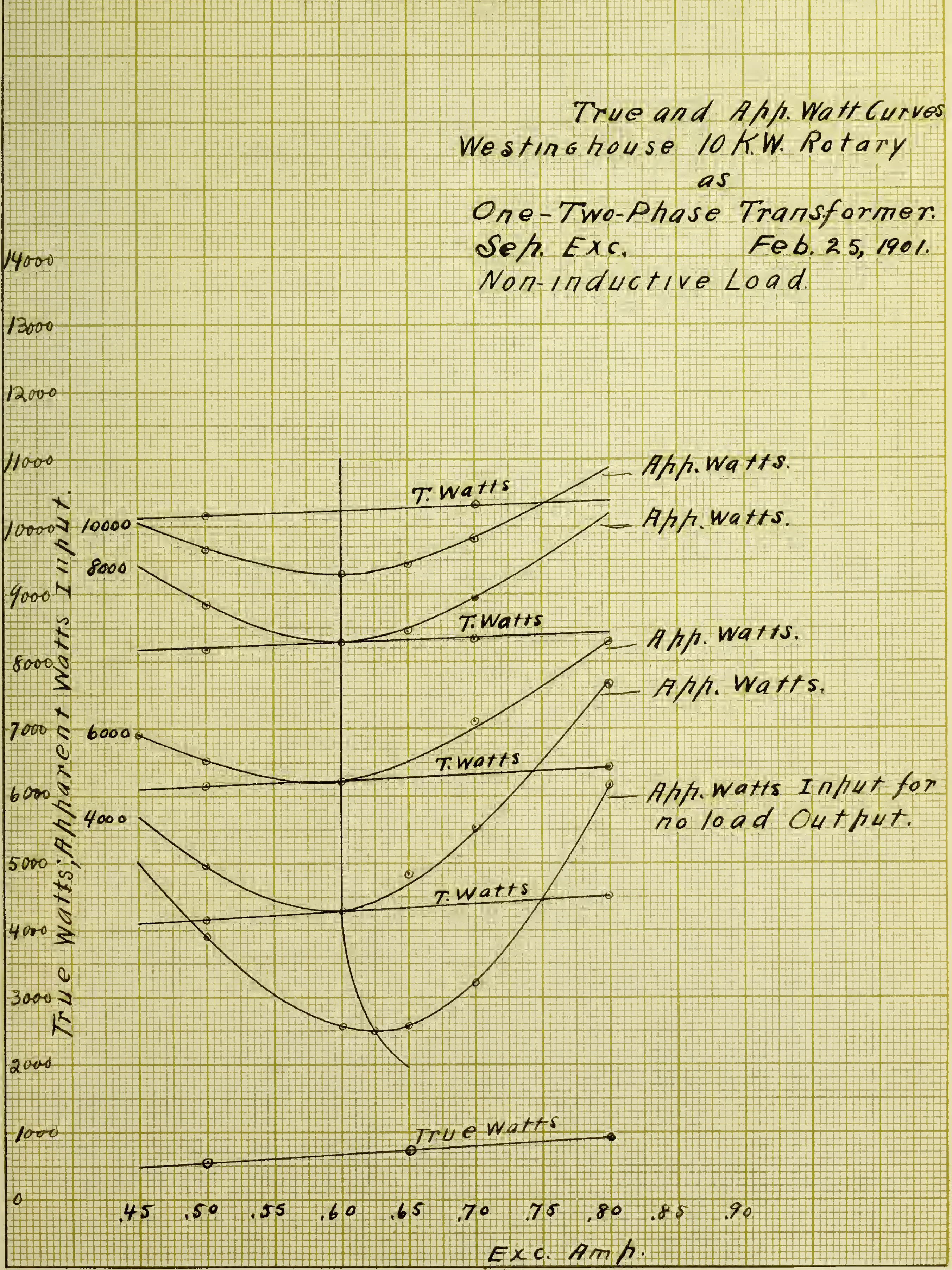
PLATE XIII.

Experiment No. 1.



True and App. Watt Curves
Westinghouse 10 K.W. Rotary
as
One-Two-Phase Transformer.
Sep. Exc. Feb. 25, 1901.
Non-inductive Load.

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PLATE XIV

Experiment No. 1 Feb. 25, 1901.

Westinghouse 10 K.W. Rotary

One-Two-Phase Transformer.

Non-inductive Load

Separately Excited

Input Current Curves.

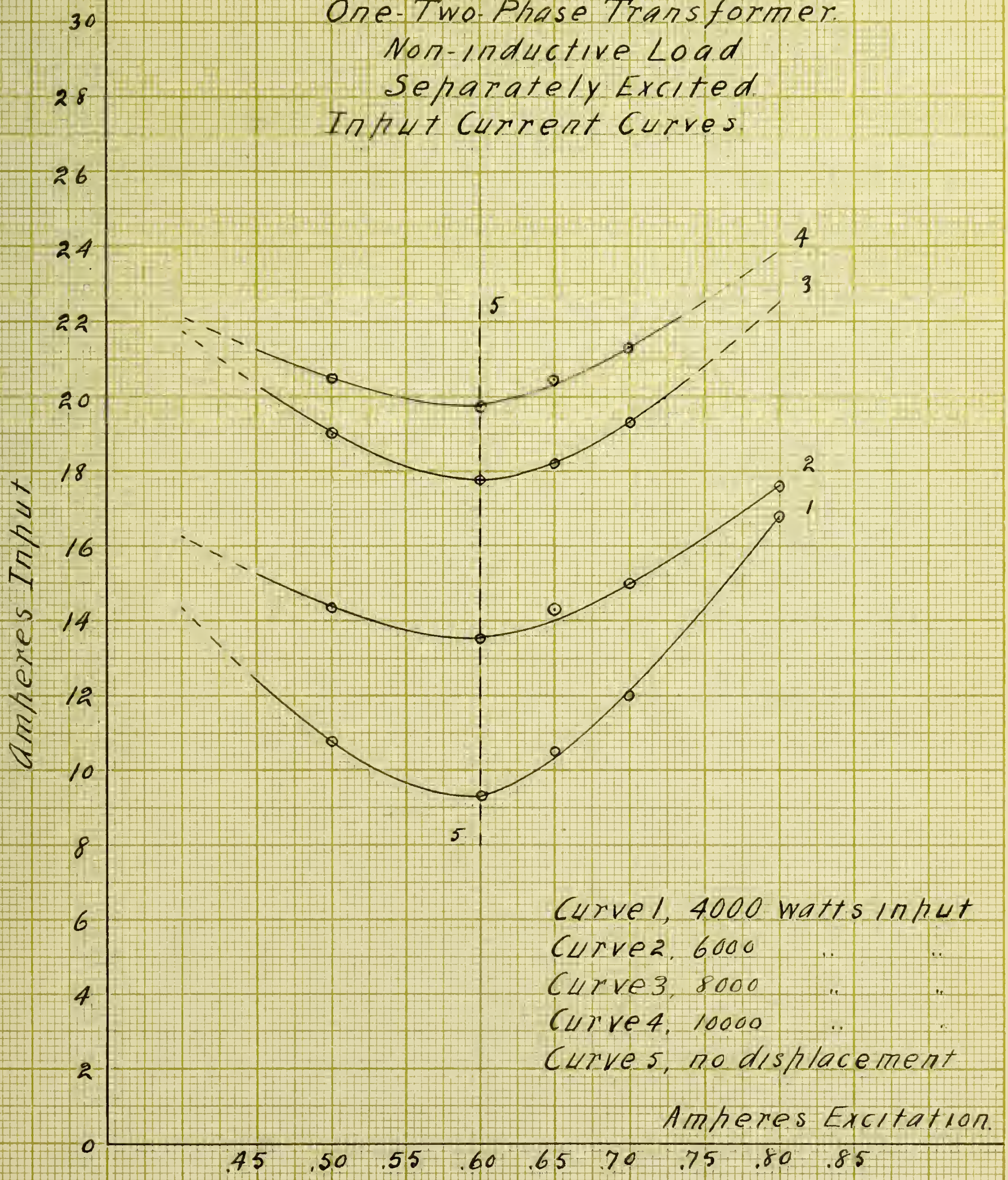
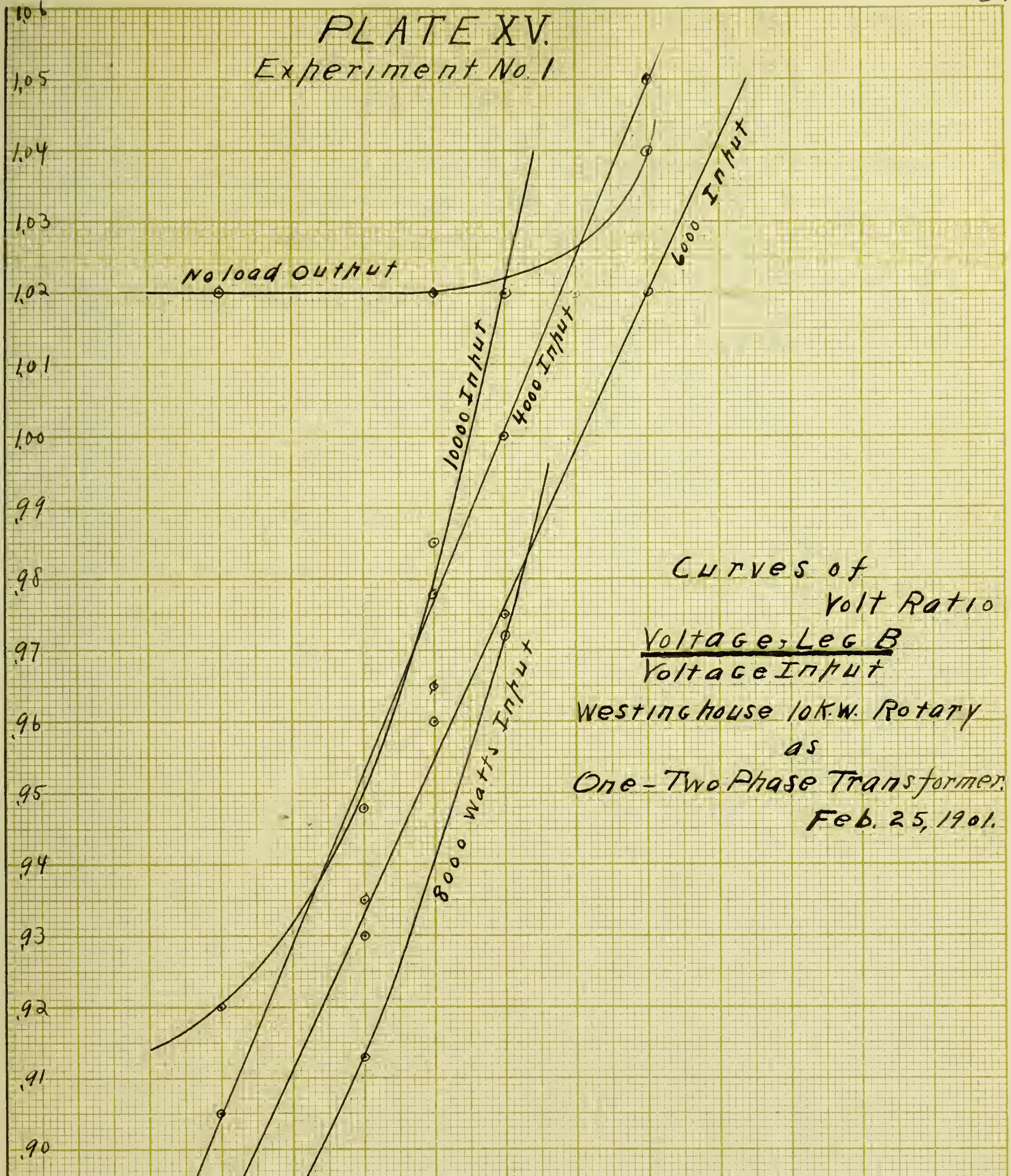


PLATE XV.

Experiment No. 1



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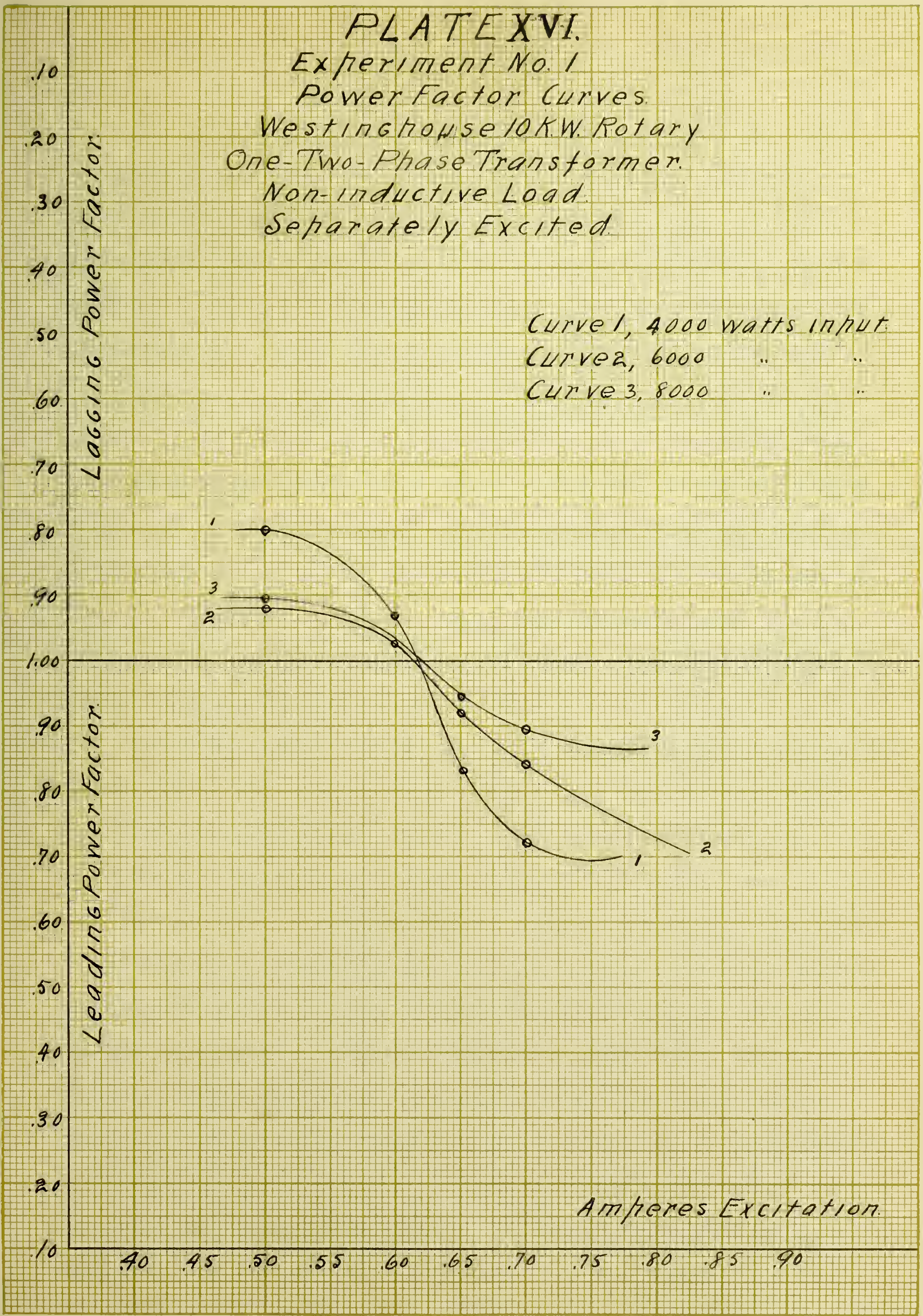

PLATE XVI.

Experiment No. 1
Power Factor Curves.
Westinghouse 10 K.W. Rotary
One-Two-Phase Transformer.
Non-inductive Load.
Separately Excited.

EUGENE DIETZGEN CO., CHICAGO.

watts lost equals the sum of the field and armature and friction loss.

In this experiment, the maximum true and apparent efficiencies are respectively 79.2 per cent and 76.2 per cent at 0.60 amperes excitation in each case respectively. This is near the normal excitation of the machine for highest power factor as shown by Plates 12, 13, 14, and 16. The lowest efficiencies and power factors occur at under-excitation and over-excitation of the field. For an under-excited field a lagging power factor prevails, while for an over-excited field a leading power factor is produced which may be the same in amount as the lagging power factor. Between those extremes an excitation may be found ar which unity power factor is approximately obtained. Plate 16 shows the excitation for unity power factor to be between 0.60 and 0.65 ampere for loads ranging between 2 kilowatts and 10 kilowatts.

Curve No.5 on Plate 14 shows the no displacement characteristic curve. All values of current to the left of this curve are for under-excitation of the field while similarly all values to the right are for over-excitation of the field. In the former case, we have a lagging phase displacement and in the latter a leading phase displacement. As the value of the lagging current decreases it finally reaches the lowest point when it begins to increase, then no longer a lagging but a leading current. Since the lowest value of the current lies always in the no displacement curve it is evident that at such points, corresponding to a certain excitation, unity power factor exists. By means of this series of curves as shown for Experiment No.1, having given any one of the following three, power factor,

excitation,or load the other two are determined directly.

35. The Voltage Regulation in this Experiment was not attempted. It will be noticed from an examination of Table III.that the input and output voltages respectively of circuit A decreased in the same ratio as the load was correspondingly increased;that is,the voltage ratio between the two is constant. In this case, the input and output leads coincide both being taken fron slip-rings 2 and 4,while the other circuit of the two-pgase output,leg B, was connected to rings1 and 3. This explains why the voltage ratio in the one case is unity while the ratio of voltage,in the leg B to that of the input varies with different loads and exciting current. As pointed out in Art.21,this connection of the circuits is evidently the most economical, giving the best heat distribution in the armature.

36. Experiment No.2.-- The same apparatus was used in this experiment as in the preceeding one. Similar sets of readings were taken with the exception that in this case the excitation of the field was varied,maintaining meanwhile a constant output. Similar curves are platted as listed for Experiment 1.page 48 the diagram of connections remaining the same. There are a few marked differences in some of the corresponding curves of each set,however. In this test(No.2) the maximum,true and apparent efficiencies more nearly approach each other,for the corresponding excitation currents. At the normal excitation of 0.60 ampere the maximum,true and apparent efficiencies are the same at full load,each being 81 per cent.

An examination of the power factor curves on Plate shows that at the normal excitation of 0.60 ampere the power factor is comparatively high for all loads. It increases from

TABLE VI. Experiment No. 2

Corrected Observations. Westinghouse 10 K.W. Rotary as One to Two-Phase Transformer. Constant Output. Non-inductive Load.

Number	INPUT			OUTPUT-A			OUTPUT-B			Exc.
	Weston	Thompson	Weston	Weston	Thompson	Weston	Weston	Thompson	Weston	Weston
	#2322	#14030	#213	#831	#13457	#1060	#857	#14010	#775	#9082
	Vm	Am	Wm	Vm	Am	Wm	Vm	Am	Wm	Am
	1	2	3	4	5	6	7	8	9	10
1	456	10	1600	455	0	0	411	0	0	0.45
2	460	6	1600	455	0	0	427	0	0	0.50
3	458	5	1640	460	0	0	435	0	0	0.55
4	459	4	1640	460	0	0	443	0	0	0.60
5	458	5.7	1720	460	0	0	452	0	0	0.65
6	456	8.7	1800	455	0	0	462	0	0	0.70
7	454	15.3	2120	455	0	0	481	0	0	0.80
8	454	18.8	2320	455	0	0	492	0	0	0.85
9	453	11.5	3600	450	2.4	1000	401	2.5	1600	0.45
10	452	8.7	3560	450	2.35	1000	416	2.55	1000	0.50
11	451	8.0	3520	450	2.35	1000	421	2.5	1000	0.55
12	451	8.4	3640	450	2.32	1000	432	2.5	1000	0.60
13	451	10	3880	450	2.4	1000	442	2.25	1000	0.65
14	450	12.5	3960	447	2.25	1000	451	2.42	1000	0.70
15	460	13.8	3880	460	2.35	1000	470	2.60	1000	0.75
16	461	16.4	4120	465	2.35	1000	480	2.20	1000	0.80
17	463	15.5	5840	465	4.4	2000	401	5.3	2000	0.45
18	463	14	5720	465	4.4	2000	412	5.05	2000	0.50
19	464	13	5640	465	4.4	2000	424	4.8	2000	0.55
20	464	12.5	5600	465	4.30	2000	435	4.7	2000	0.60
21	463	13.3	5680	465	4.34	2000	445	4.5	2000	0.65
22	463	15	5800	465	4.27	2000	455	4.45	2000	0.70
23	462	16.7	5880	455	4.30	2000	464	4.2	2000	0.75
24	461	19.8	6200	473	4.34	2000	476	4.3	2000	0.80
25	459	20	7880	460	6.35	3000	393	7.5	3000	0.45

Table VI. (continued)

	1 Vm	2 Am	3 Wm	4 Vm	5 Am	6 Wm	7 Vm	8 Am	9 Wm	10 Am
26	465	18.2	7760	468	6.34	3000	411	7.4	3000	0.50
27	462	17.5	7880	465	6.44	3000	417	7.3	3000	0.55
28	462	17.2	7920	465	6.50	3000	436	7.3	3000	0.60
29	462	17.5	7720	465	6.37	3000	438	6.8	3000	0.65
30	461	19.2	8000	463	6.40	3000	446	7.0	3000	0.70
31	461	21.2	8160	460	6.43	3000	458	6.75	3000	0.75
32	460	23	8240	458	6.35	3000	466	6.55	3000	0.80
33	458	23.8	9880	455	8.56	4000	381	10.5	4000	0.45
34	456	22.5	9800	455	8.60	4000	396	10.0	4000	0.50
35	458	22	9840	458	8.46	4000	406	9.8	4000	0.55
36	460	21.8	9920	461	8.55	4000	419	9.6	4000	0.60
37	460	22	9880	463	840	4000	430	9.1	4000	0 65
38	462	23.4	10000	464	8.40	4000	442	8.9	4000	0 70
39	457	26.7	11880	455	10.7	5000	401	12.0	5000	0 55
40	464	26	12000	465	10.4	5000	416	11.9	5000	0.60
41	456	27.5	11920	455	10.6	5000	421	11.5	5000	0.65

TABLE VII.

Calculated Results of Experiment No. 2.

Number	1 App. Watts Input	2 Input Power Factor	3 Watts Field Loss	4 Total Watts Input	5 Total Watts Output	6 True Efficiency	7 App. Efficiency	8 Volt Ratio A	9 Volt Ratio B	10 Watts Lost No Load.
1	4560	0.35	138	1738	0	0	0	1	0.88	1738
2	2760	0.58	170	1770	0	0	0	1	0.925	1770
3	2290	0.71	206	1846	0	0	0	1	0.95	1846
4	2836	0.884	245	1885	0	0	0	1	0.966	1885
5	2615	0.66	387	2007	0	0	0	1	0.984	2007
6	3970	0.453	333	2133	0	0	0	1	1.02	2133
7	6940	0.306	435	2555	0	0	0	1	1.06	2555
8	8500	0.273	490	2810	0	0	0	1	1.08	2810
9	5200	0.693	138	3738	2000	0.535	0.371	1	0.885	—
10	3940	0.905	170	3730	2000	0.537	0.485	1	0.92	—
11	3608	0.975	206	3726	2000	0.538	0.525	1	0.934	—
12	3790	0.96	245	3885	2000	0.515	0.495	1	0.956	—
13	4510	0.86	287	4167	2000	0.48	0.412	1	0.98	—
14	5625	0.705	333	4293	2000	0.466	0.328	1	1.00	—
15	6350	0.61	382	4262	2000	0.47	0.286	1	1.02	—
16	5760	0.545	435	4555	2000	0.44	0.240	1	1.045	—
17	7175	0.815	138	5978	4000	0.67	0.545	1	0.865	—
18	6475	0.883	170	5790	4000	0.68	0.60	1	0.89	—
19	6040	0.935	206	5846	4000	0.685	0.64	1	0.915	—
20	5800	0.965	245	5845	4000	0.685	0.66	1	0.937	—
21	6160	0.922	287	5967	4000	0.672	0.62	1	0.96	—
22	6950	0.835	933	6133	4000	0.653	0.545	1	0.982	—
23	7700	0.765	382	6262	4000	0.64	0.49	1	1.01	—
24	9130	0.68	435	6635	4000	0.603	0.41	1	1.03	—
25	9180	0.86	138	8018.	6000	0.75	0.645	1	0.856	—

Table VII.(continued)

Number	1 Apparent Watts Input	2 Power Factor	3 Watts Field Loss	4 Total Watts Input	5 Total Watts Output	6 True Efficiency	7 Apparent Efficiency	8 Volt Ratio Phase A	9 Volt-Ratio Phase B	10 Watts Lost No Load
26	8450	0.92	170	7930	6000	0.756	0.695	1	0.863	—
27	8090	0.975	206	8086	6000	741	0.722	1	0.88	—
28	7950	0.995	245	8165	6000	735	0.732	1	0.945	—
29	8090	0.953	287	8007	6000	75	0.715	1	0.95	—
30	8850	0.905	333	8333	6000	72	0.65	1	0.966	—
31	9780	0.835	382	8542	6000	703	0.59	1	0.994	—
32	10600	0.777	435	8675	6000	692	0.538	1	1.01	—
33	10900	0.91	138	10018	8000	80	0.728	1	0.832	—
34	10250	0.955	170	9970	8000	803	0.767	1	0.87	—
35	10200	0.965	206	10046	8000	795	0.767	1	0.888	—
36	10020	0.99	245	10165	8000	788	0.78	1	0.91	—
37	10100	0.98	287	10167	8000	788	0.772	1	0.935	—
38	10800	0.926	333	10333	8000	775	0.72	1	0.956	—
39	12200	0.975	206	12086	10000	828	0.807	1	0.88	—
40	12040	0.995	245	12245	10000	816	0.812	1	0.898	—
41	12550	0.95	287	12207	1000	82	0.78	1	0.905	—

TABLE VIII.

Values to be Platted for Experiment No. 2

Number	1 Power Factor	2 True Efficiency	3 App. Efficiency	4 Volt Ratio Phase A	5 Watts Field Loss	6 Volt Ratio Phase B	7 Armature and Friction Loss	8 Total Watts Lost	9 Input Amperes	10 Watts Output	11 Amperes Excitation
1	0.35	0	0	1	138	0.88	1600	1738	16	0	0.45
2	0.58	0	0	1	170	0.925	1600	1770	6	0	0.50
3	0.71	0	0	1	206	0.95	1640	1846	5	0	0.55
4	0.884	0	0	1	245	0.966	1640	1885	4	0	0.60
5	0.66	0	0	1	287	0.984	1720	2007	5.7	0	0.65
6	0.453	0	0	1	333	1.02	1800	2133	8.7	0	0.70
7	0.306	0	0	1	435	1.06	2120	2555	15.3	0	0.80
8	0.273	0	0	1	490	1.08	2320	2810	18.8	0	0.85
9	0.693	0.535	0.371	1	—	0.885	—	—	11.5	2000	0.45
10	0.905	0.537	485	1	—	0.92	—	—	8.7	2000	0.50
11	0.975	0.538	525	1	—	0.934	—	—	8.0	2000	0.55
12	0.96	0.515	445	1	—	0.956	—	—	8.4	2000	0.60
13	0.86	0.48	412	1	—	0.98	—	—	10.0	2000	0.65
14	0.705	0.466	328	1	—	1.00	—	—	12.5	2000	0.70
15	0.61	0.47	286	1	—	1.02	—	—	13.8	2000	0.75
16	0.545	0.44	24	1	—	1.045	—	—	16.4	2000	0.80
17	0.815	0.67	545	1	—	0.865	—	—	15.5	4000	0.45
18	0 883	0.68	60	1	—	0.89	—	—	14.0	4000	0.50
19	0.935	0.685	64	1	—	0.915	—	—	13.0	4000	0.55
20	0.965	0.675	66	1	—	0.937	—	—	12.5	4000	0.60
21	0.922	0.672	62	1	—	0.96	—	—	13.3	4000	0.65
22	0.835	0.653	545	1	—	0.982	—	—	15	4000	0.70
23	0.765	0.64	49	1	—	1.01	—	—	16.7	4000	0 75
24	0.68	0.603	41	1	—	1.03	—	—	19.8	4000	0.80
25	0.86	0.75	645	1	—	0.856	—	—	20	6000	0 45

TABLE VIII. (continued)

No	1	2	3	4	5	6	7	8	9	10	11
26	0.92	0.756	0.695	1	—	0.863	—	—	18.2	6000	0.50
27	975	741	722	1	—	88	—	—	17.5	6000	0.55
28	995	735	732	1	—	945	—	—	17.2	6000	0.60
29	953	75	715	1	—	95	—	—	17.5	6000	0.65
30	905	72	65	1	—	966	—	—	19.2	6000	0.70
31	835	703	59	1	—	994	—	—	21.2	6000	0.75
32	777	692	538	1	—	1.01	—	—	23.0	6000	0.80
33	91	80	728	1	—	832	—	—	23.8	8000	0.45
34	955	803	767	1	—	87	—	—	22.5	8000	0.50
35	965	795	767	1	—	888	—	—	22.0	8000	0.55
36	99	788	78	1	—	91	—	—	21.8	8000	0.60
37	98	788	772	1	—	935	—	—	22.0	8000	0.65
38	926	775	72	1	—	956	—	-	23.4	8000	0.70
39	975	828	807	1	—	88	—	-	26.7	10000	0.55
40	995	816	812	1	—	898	—	—	26.0	10000	0.60
41	95	82	78	1	—	905	—	—	27.5	10000	0 65

PLATE XVII.

Experiment No. 2 - Feb. 27, 1901.
Curves of Watts Lost.
Westinghouse 10 K.W. Rotary
One-Two-Phase Transformer.
Non-inductive Load, Constant Output.
Separately Excited.

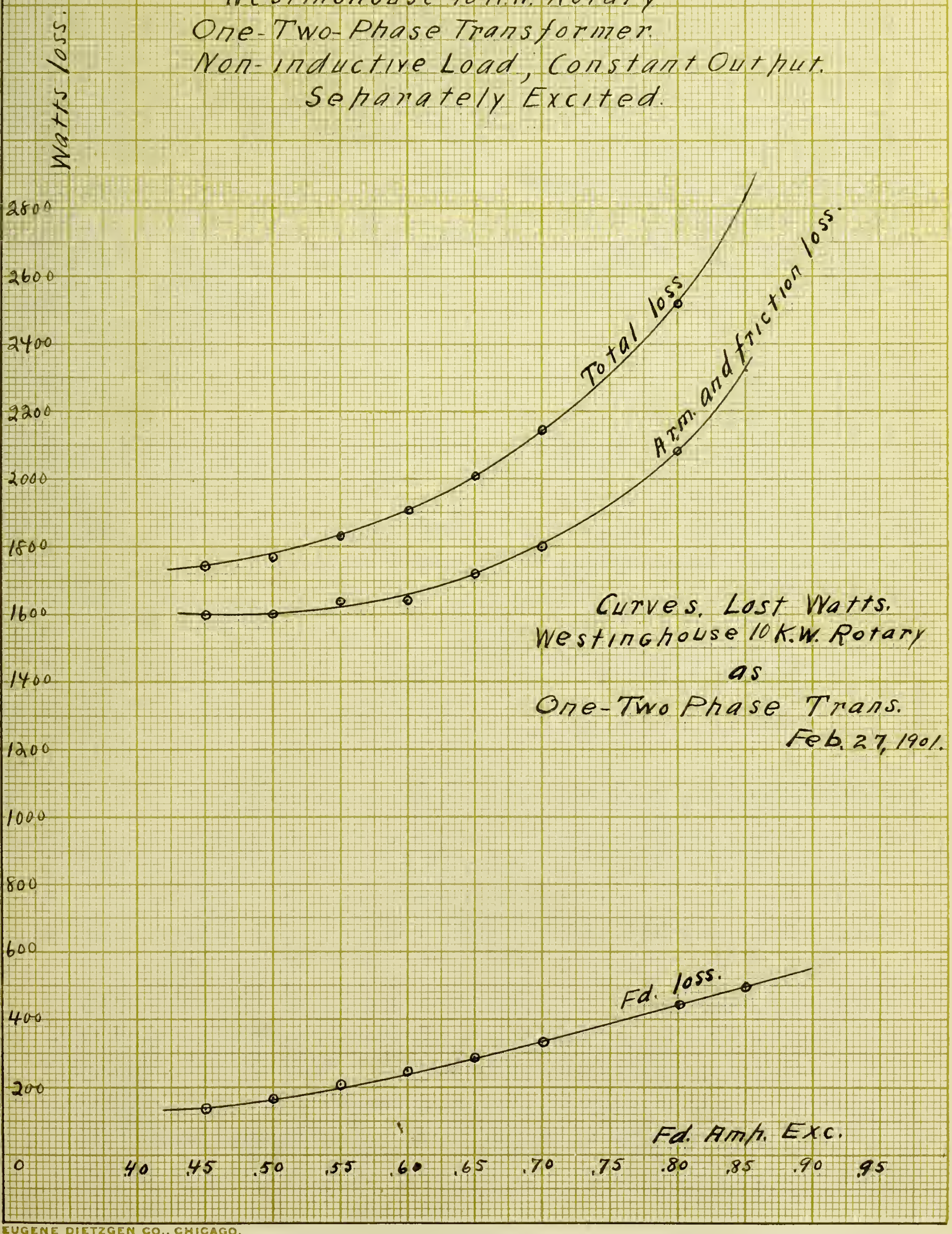

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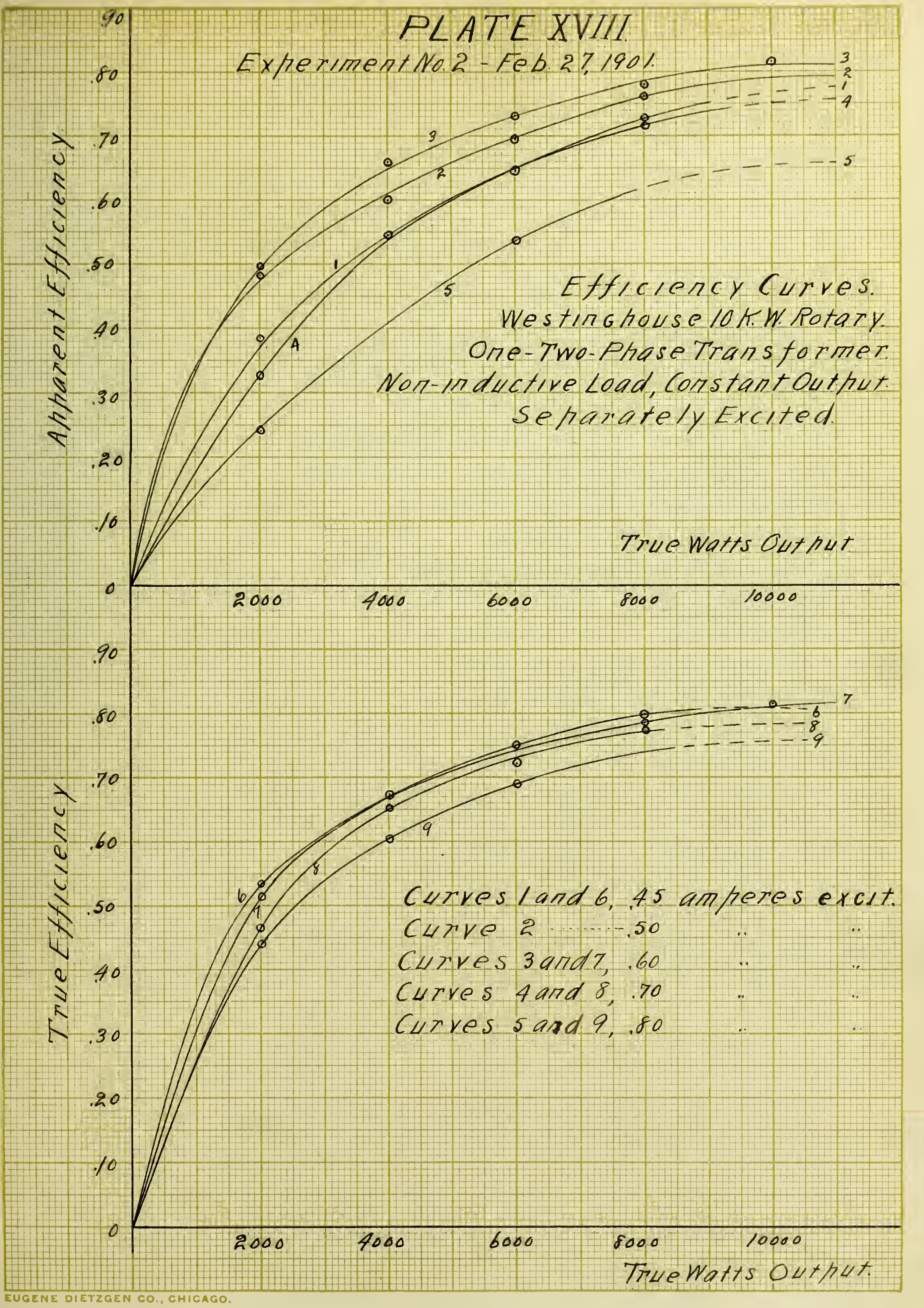
PLATE XVIII

Experiment No. 2 - Feb. 27, 1901.



Efficiency Curves.
Westinghouse 10 K.W. Rotary.
One-Two-Phase Transformer.
Non-inductive Load, Constant Output.
Separately Excited.

Curves 1 and 6, .45 amperes excit.
Curve 2 .50 " "
Curves 3 and 7, .60 " "
Curves 4 and 8, .70 " "
Curves 5 and 9, .80 " "

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PLATE XIX.

Experiment No. 2, Feb. 27, 1901.

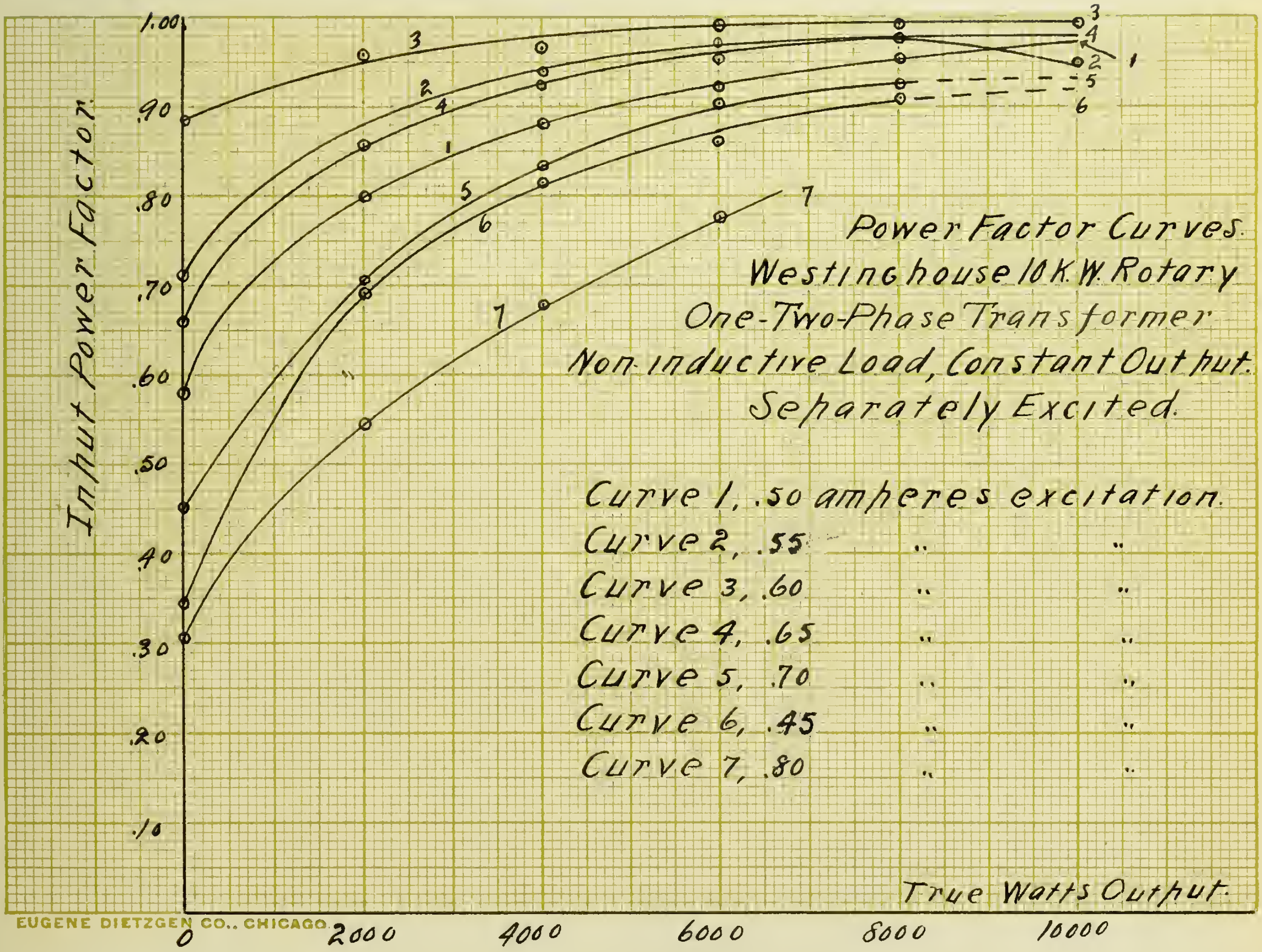

PLATE XX.

Experiment 2 - Feb. 27, 1901.

Input-Ampere Curves.

Westinghouse 10 K.W. Rotary, Separately Excited.
One-Two-Phase Transformer
Non-inductive Load- Constant Output.

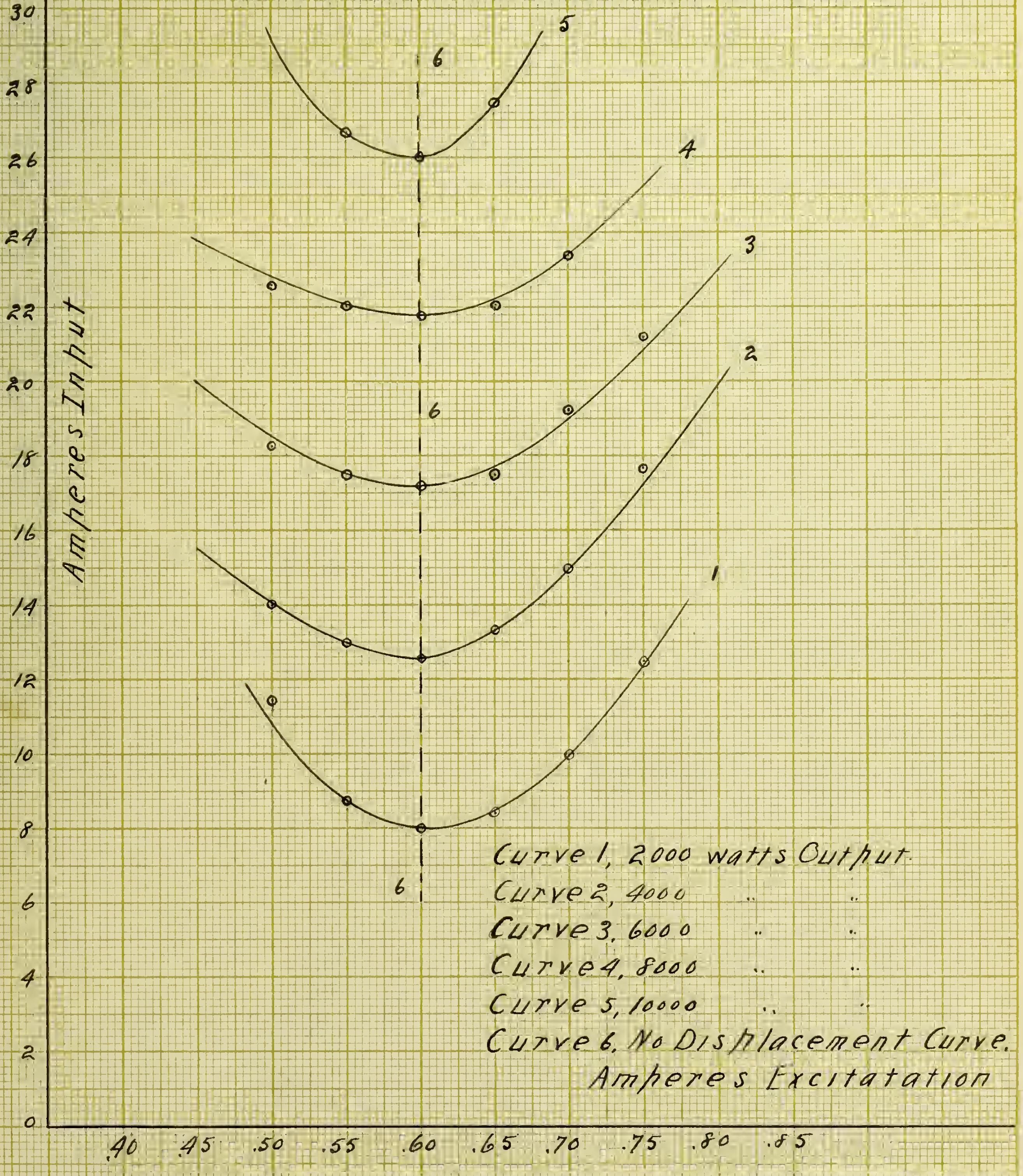

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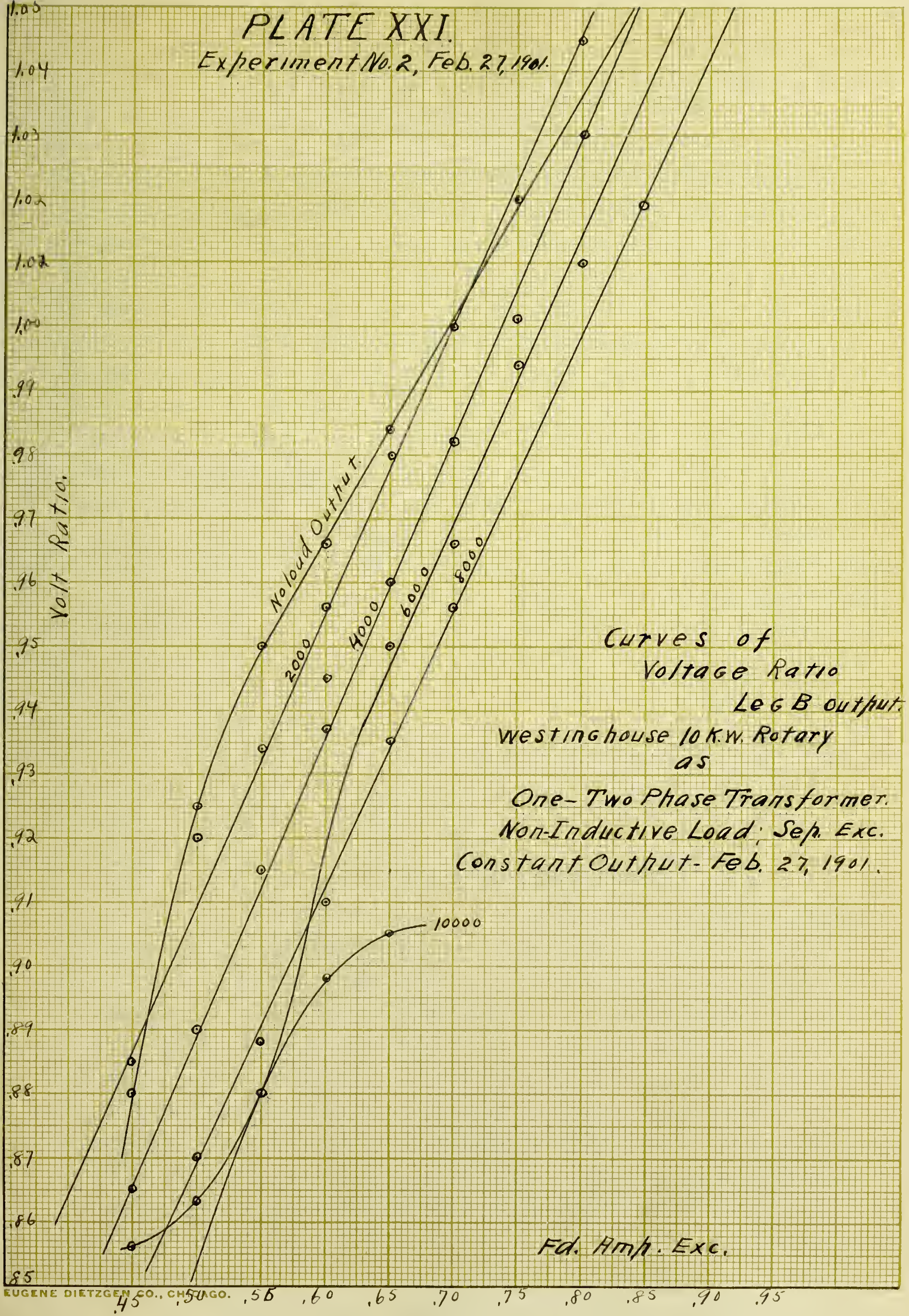
PLATE XXI.

Experiment No. 2, Feb. 27, 1901.

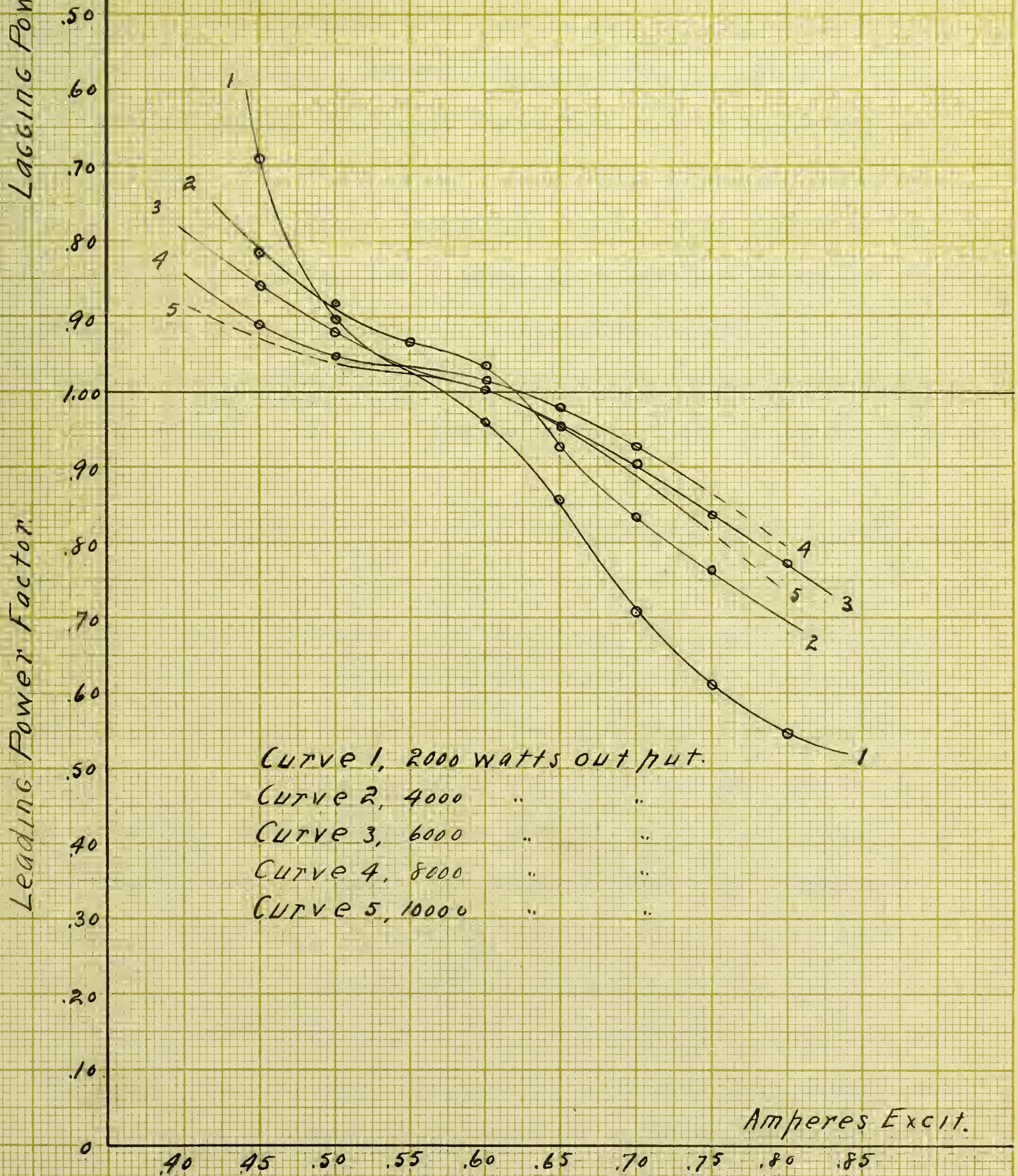


Curves of
Voltage Ratio
Leg B output.
Westinghouse 10 K.W. Rotary
as
One-Two Phase Transformer.
Non-Inductive Load; Sep. Exc.
Constant Output - Feb. 27, 1901.

EUGENE DIETZGEN CO., CHICAGO.

PLATE XXII.

Experiment No. 2, Feb. 27, 1901.
Input Power Factor Curves.
Westinghouse 10 K.W. Rotary
One-Two-Phase Transformer.
Non-inductive Load, Constant Output.
Separately Excited.



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98 per cent at 2/5 full load to 99.5 per cent at 4/5 full load, maintaining this value up to full load with no apparent decrease At an under-excitation of 0.55 ampere a maximum power factor of .97.5 per cent is reached at 4/5 full load when it decreases to 94.5 per cent at full load. This drooping of the power factor curve before reaching full load is not characteristic of the curves for other values of the exciting current.

Plate 22 shows the phase characteristic of power factor for variable excitation. At 1/5 full load,unity power factor occurs at 0.5725 ampere excitation; at 2/5 full load,0.62 ampere excitation; at 3/5 full load, 0.605 ampere excitation; at 4/5 full load,0.625 ampere excitation and at full load of 10 kilowatts unity power factor occurs at 0.605 ampere excitation.

The voltage ratios follow the same law as in the preceeding experiment.

37. Experiment No.3.-- One to Three-Phase Transformation. The machine used in this experiment was a 7 1/2 kilowatt General Electric rotary converter referred to in Art.19. There are two converters of this type in the Electrical Engineering laboratoryhaving the same capacity and so situated with respect to each other as a motor-generator unit. This machine as a phase converter was operated self-excited with th e other rotary as a variable reactive load. The second rotary was loaded by a bank of incandescent lamps in parallel with a water rheostat and was kept at a constant under-excitation of 1.0 ampere throughout the test. Readings were taken for constant excitation of 1.0, 1.4, 1.6, 1.8, and 1.95 amperes respectively,for all loads up to the limit allowed by the current aarrying capacity of the armature. The following curves are platted:

PLATE XXII. Experiment No. 3

General Electric $7\frac{1}{2}$ K.W. Rotary Converter as One to Three Phase Transformer. Self Excited. Inductive Load.

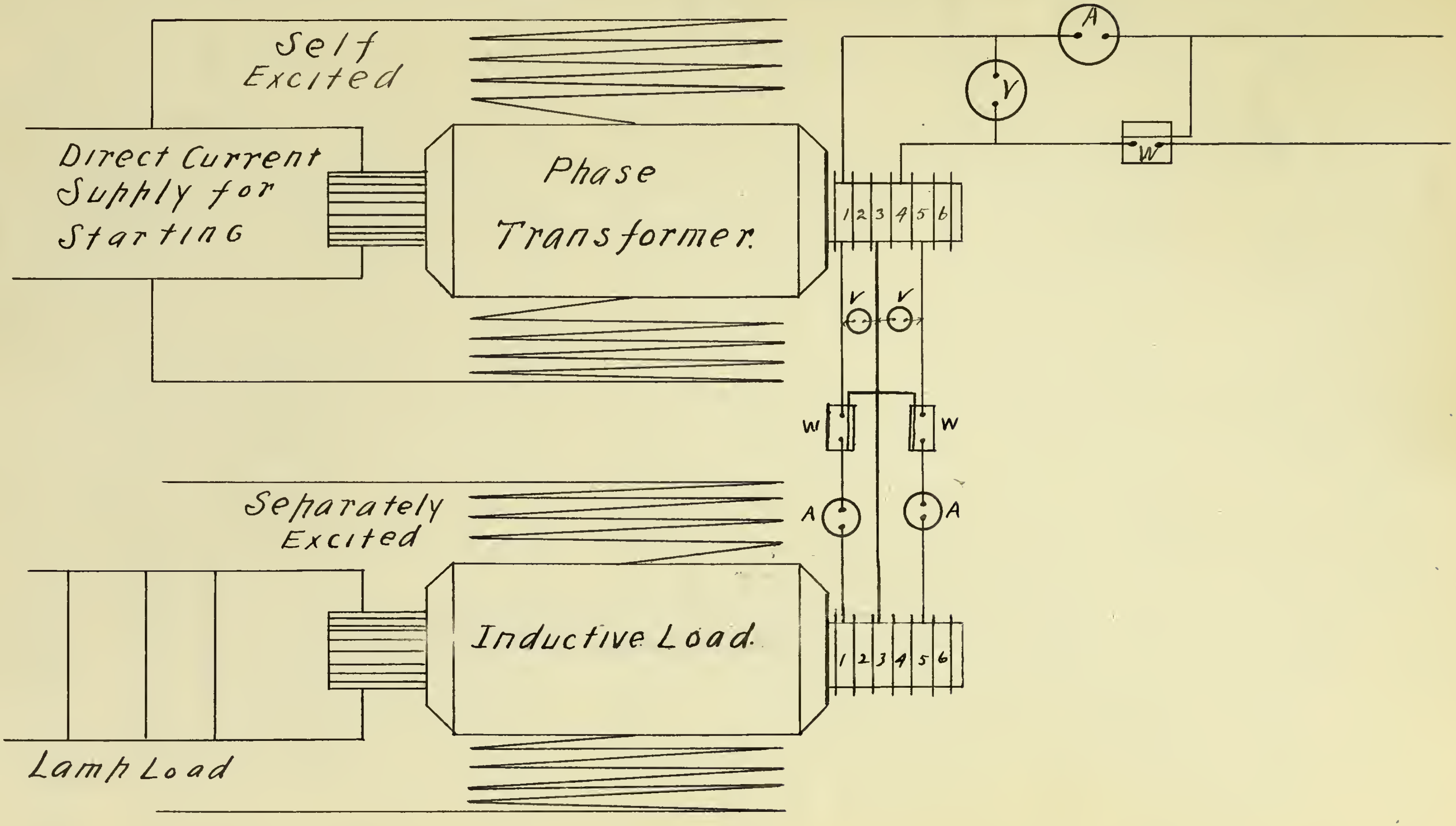


FIG. 36

Plate 24 ,No Load Curves,Excitation Base.

Plate 25 , Input Power Factor,True Watts Input Base.

Plate 23 , Voltage Ratios,True Watts Input Base.

Plate 23 , True Efficiencies,True Watts Input Base.

38. The input voltage was kept as nearly constant as possible at 110 volts. In a balanced system the output voltage for each separate phase of the three-phase circuit should be 110 X $1/2\sqrt{3}$ or 94.6 volts. The voltage ratio for phase A varied much more than that of phase B. Furthermore, the voltage in phase B increases more rapidly as the excitation or load is increased,than it does in phase A. This produces a greater difference of voltage between the two branches of the three-phase circuit. When each phase of the external circuit was equally loaded the observed output voltages wer not the same as required by the theoretical ratio. They should be,however, practically realized if the connections between slip-rings and armature winding are properly made for a true three-phase circuit.

39. Referring furthermore to the power factor curves platted for Experiment 3,or true watts input base it will be seen that as the excitation is increased for all loads the power factor correspondinglt increases. The power factor for full load output was not obtained because of the excessive current required in the armature at that load. The highest power afctor was/96 per cent at almost 10 kilowatts input for an excitation of 1.95 amperes. The corresponding efficiency for the same load and excitation was 76 per cent.

The highest maintained efficiency occurred at 1.4 amperes excitation. The maximum efficiency for any excitation was not

TABLE IX. Corrected Observations.

Experiment No. 3. General Electric Rotary as a One to Three-Phase Transformer. Self Excited. Inductive Load.

Number	INPUT			OUTPUT A			OUTPUT B			Exc.
	Weston	Thompson	Weston	Weston	Thompson	Weston	Weston	Thompson	Weston	Weston
	#2322	13469	#775	#2882	14008	1060	#857	#14010	#213	#9082
	Vm	am	Wm	Vm	am	Wm	Vm	Am	Wm	Am
	1	2	3	4	5	6	7	8	9	10
1	111	27.5	1100	90.5	0	0	91	0	0	1.0
2	111	27.5	1080	90.5	0	0	91	0	0	1.0
3	111	27.5	1100	90.5	0	0	91	0	0	1.0
4	111	20	1200	92	0	0	94.5	0	0	1.4
5	110.3	18	1180	92	0	0	94.5	0	0	1.4
6	111	17	1200	91.5	0	0	95	0	0	1.4
7	110.7	16	1220	93	0	0	97	0	0	1.6
8	110.7	16	1240	93	0	0	97	0	0	1.6
9	111	15	1240	93	0	0	97	0	0	1.6
10	110.5	24	1340	94	0	0	99	0	0	1.8
11	110.5	24	1330	94	0	0	99	0	0	1.8
12	110.5	—	1320	94	0	0	99	0	0	1.8
13	111	35	1480	94.5	0	0	100.5	0	0	1.98
14	111	35	1490	94.4	0	0	100.5	0	0	1.98
15	111	35	1480	94.5	0	0	100.5	0	0	1.98
16	110	66	2350	88	40	750	89	37.5	1100	1.0
17	110	66	2400	89	40	750	89	37	1000	1.0
18	109.5	67	4000	86	42	800	89.5	42.5	1550	1.0
19	109.5	67	4040	86.4	42	800	89	43	1500	1.0
20	109.5	67	4060	86.4	42	800	89.5	43	1500	1.0
21	110.5	76	5600	84.6	47	1700	89.5	51	2300	1.0
22	110.5	76	5650	84	47	1700	89.5	50.5	2300	1.0
23	110.5	76	5620	84.2	47	1700	90	50.5	2250	1.0
24	111	86	7200	82.8	51	2650	90.5	61.5	2700	1.0
25	111.2	88	7100	82.8	52	2600	90.5	61	2700	1.0
26	111.5	87	7100	83	51	2600	90.5	61.5	2700	1.0
27	111	90	7700	82	53	2950	90.5	65.5	3200	1.0
28	111	90	7650	82	54	2900	90.5	64.5	3150	1.0
29	111	88	7600	82.4	53	2850	90.5	63	3100	1.0
30	110.9	82	8200	82.8	65	4250	93	60	2250	1.4

TABLE IX. (continued).

	1	2	3	4	5	6	7	8	9	10
No	Vm	am	Wm	Vm	am	Wm	Vm	am	Wm	am
31	110.7	83	8300	82	63	4250	93	58	2250	1.4
32	110.3	84	8400	82	65	4300	93	58.5	2300	1.4
33	110.5	75	7100	83.6	60	3550	92.5	53.5	1800	1.4
34	110.5	71	7100	83.2	59	3600	92.5	52	1800	1.4
35	110.5	72	7100	83	60	3600	92.5	53	1850	1.4
36	111	66	6100	85.4	55	3000	93	49.5	1500	1.4
37	111	65	6100	85	55	3050	92.5	49	1550	1.4
38	111	64	6100	85.2	55	3050	92.5	50	1550	1.4
39	111.3	58	5120	87	51	2450	92.5	44	1150	1.4
40	111.5	59	5100	86.8	50	2400	92.5	44.5	1150	1.4
41	111.5	59	5110	87	51	2450	92.5	43.5	1100	1.4
42	111.5	53	4040	87.5	47	1850	92	40.5	750	1.4
43	111.2	53	4020	88	48	1850	92	42.5	800	1.4
44	111	53	4060	88	48	1850	92	42.7	800	1.4
45	112.5	50	2400	91	46	900	91.5	40	400	1.4
46	112.5	49	2420	91	47	900	91.5	39.5	400	1.4
47	111	45	2380	90	45	900	92	39.5	400	1.4
48	111	37	2400	90	46	1400	92	39	400	1.6
49	111	37	2380	90.4	46	1400	92.5	39	400	1.6
50	111	36	2400	90.6	46	1400	93	39	400	1.6
51	110.5	44	4150	88	50	2400	93	41	600	1.6
52	110.5	45	4160	87	50	2400	93	40.5	600	1.6
53	110.5	46	4200	88	51	2400	93	41.5	600	1.6
54	110.3	53	5140	86.4	54	2950	93	42.5	700	1.6
55	110.2	54	5100	86	55	2950	93	44	700	1.6
56	110.2	53	5160	86.2	56	2900	93.5	44.5	650	1.6
57	111	63	6250	85.4	59	3500	93.5	48	1100	1.6
58	111	64	6300	85.6	60	3500	93.5	48.5	1100	1.6
59	111	63	6260	85.3	60	3550	93.5	48.5	1050	1.6
60	111.5	70	7100	84.8	63	4000	94	51	1350	1.6

TABLE IX (continued)

	1	2	3	4	5	6	7	8	9	10
No	Vm	am	Wm	Vm	Am	Wm	Vm	am	Wm	Am
61	111.5	72	7100	84.6	63	4000	94	52.5	1350	1.6
62	111.5	72	7100	84.6	64	4000	94	52.5	1350	1.6
63	111	78	8280	82.8	67	4550	94	57	1750	1.6
64	110.5	80	8200	82.6	68	4600	94	57	1750	1.6
65	110.5	80	8300	82.6	68	4700	94	57	1750	1.6
66	111	88	8800	82	75	5500	95	60	1450	1.8
67	111	90	8700	82	75	5450	95	58.5	1450	1.8
68	111	94	8800	82	—	—	95	59.5	1450	1.8
69	110.5	30.5	2700	91	51	2000	93.5	41	-800	1.8
70	110.5	32	2900	89	52	2100	93	42.5	-750	1.8
71	110.5	34	2900	90	52	2100	93	41	-700	1.8
72	110.5	43	4200	88	55	2650	93.5	42	-400	1.8
73	110.5	44	4200	88	56	2650	93.5	42.5	-400	1.8
74	110.5	43	4200	88	55	2750	93.5	42.5	-400	1.8
75	110.5	65	6700	85	66	4200	94	49.5	+700	1.8
76	110.5	63	6700	85	66	4200	94.5	50	700	1.8
77	110.5	66	6800	85	67	4200	94.5	51	750	1.8
78	110.5	80	8500	83	73	5200	95	56.5	±	1.8
79	110.5	27	2600	90.5	53	2300	94	44	-1250	1.95
80	110.5	27	2600	90.5	53	2300	94	44	-1250	1.95
81	110.5	27	2600	91	52	2350	94	44	-1250	1.95
82	110.5	45	4500	88.5	62	3500	95	48.5	-300	1.95
83	110.5	45	4500	88	62	3400	95	49	-300	1.95
84	110.5	45	4500	88	62	3250	95	49	-300	1.95
85	110.5	62	6500	85	68	4250	94	50	+250	1.95
86	110.5	64	6700	85	71	4400	94	52	600	1.95

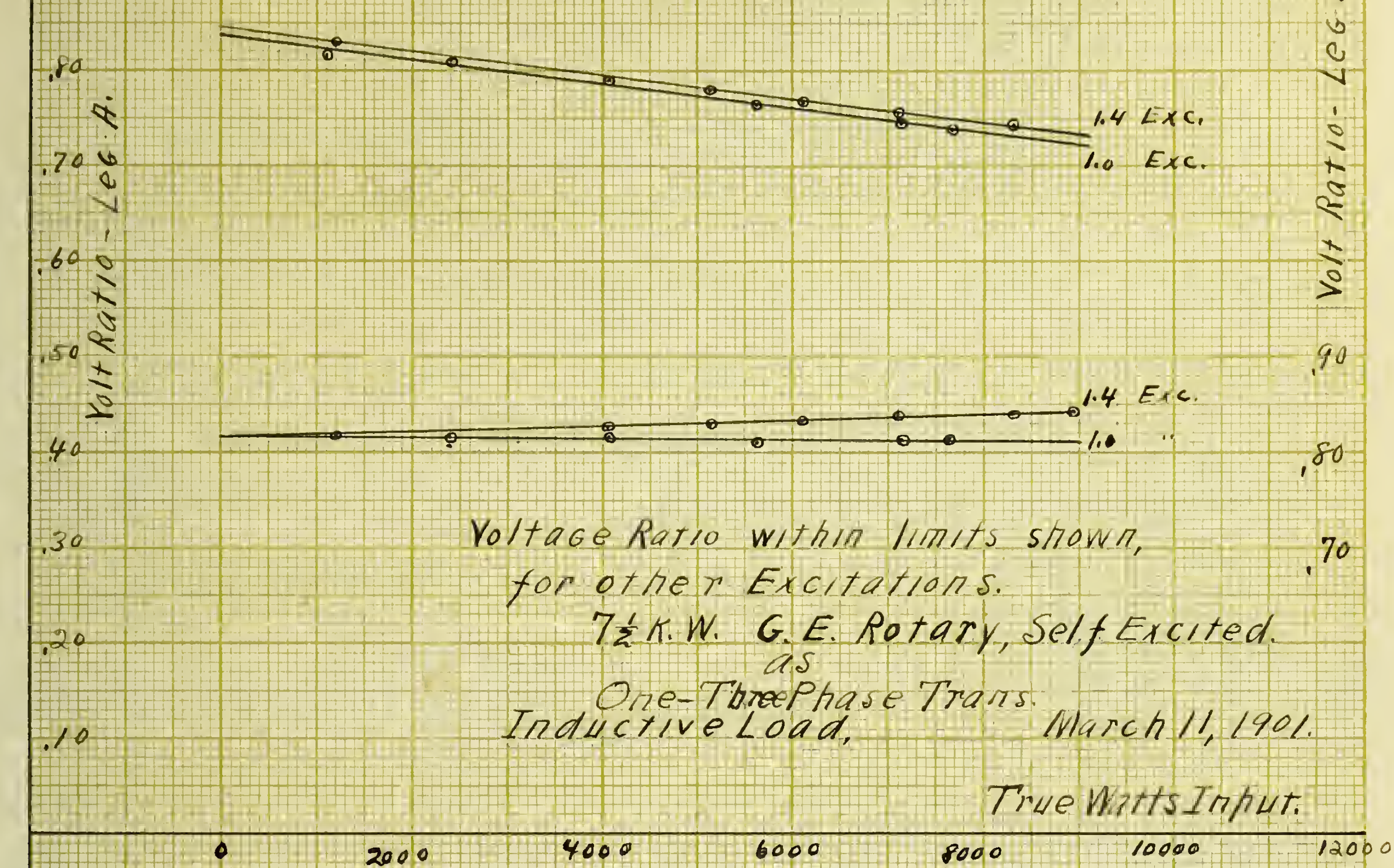
TABLE X.

Calculated and Platted Results for Experimen No. 3.

Number	1	2	3	4	5	6	7	8	9
	App. Watts Input	True Watts Input	Input Power Factor	True Watts Output	True Efficiency	Volt Ratio A	Volt Ratio B	Amperes Input	Amperes Excitation
1	3050	1100	0.36	0	0	0.815	0.82	27.5	1.0
2	2000	1200	60	0	0	83	855	18.7	1.4
3	1770	1240	70	0	0	837	874	16	1.6
4	2660	1330	50	0	0	846	89	24	1.8
5	3880	1480	382	0	0	852	904	35	1.98
6	7260	2375	327	1800	0.76	805	808	66	1.0
7	7230	4040	56	2320	575	79	817	67	1.0
8	8400	5630	67	4000	71	764	81	76	1.0
9	9670	7130	75	5320	745	745	813	87	1.0
10	9990	7650	766	6050	79	738	815	90	1.0
11	9200	8300	90	6550	79	742	84	83	1.4
12	8070	7100	88	5400	76	754	838	73	1.4
13	7215	6100	845	4600	755	767	833	65	1.4
14	6570	5110	78	3550	696	78	83	59	1.4
15	5900	4040	685	2650	656	79	826	53	1.4
16	5400	2400	445	1300	542	81	818	49	1.4
17	4100	2410 2180	585	1800	75	815	834	37	1.6
18	4975	5140	845	3000	718	795	84	45	1.6
19	5940	6280	865	3600	702	782	845	53	1.6
20	7000	7100	898	4600	732	77	842	63	1.6
21	8020	8270	887	5350	754	766	844	72	1.6
22	8850	8780	934	6350	77	75	84	80	1.8
23	10100	2850	87	6925	789	74	856	91	1.8
24	3540	4200	82	1350	475	815	84	32	1.8
25	4750	6780	885	2250	536	796	846	43	1.8
26	7200	8500	937	4900	723	77	855	65	1.8
27	8850	2600	96	—	—	75	86	80	1.8
28	2980	4500	873	1100	423	82	84	27	1.95
29	4970	6600	905	3100	69	796	86	45	1.95
30	6960	—	948	5000	747	77	84	63	1.95

PLATE XXIII.

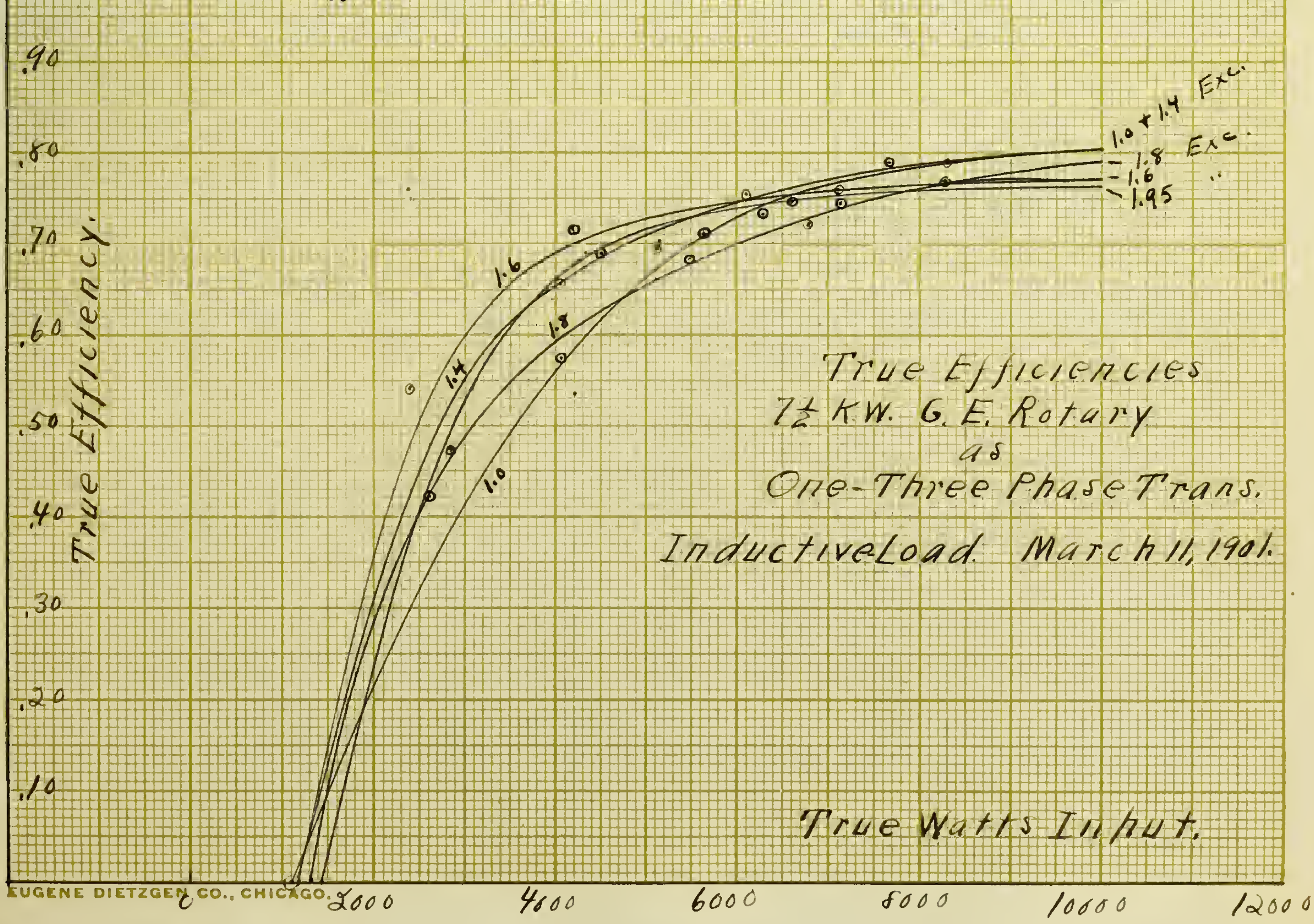
Experiment No. 3, March 11, 1901.



Voltage Ratio within limits shown, for other Excitations.

7½ K.W. G.E. Rotary, Self Excited. as One-~~Three~~ Phase Trans.

Inductive Load, March 11, 1901.



True Efficiencies 7½ K.W. G.E. Rotary as One-Three Phase Trans.

Inductive Load. March 11, 1901.

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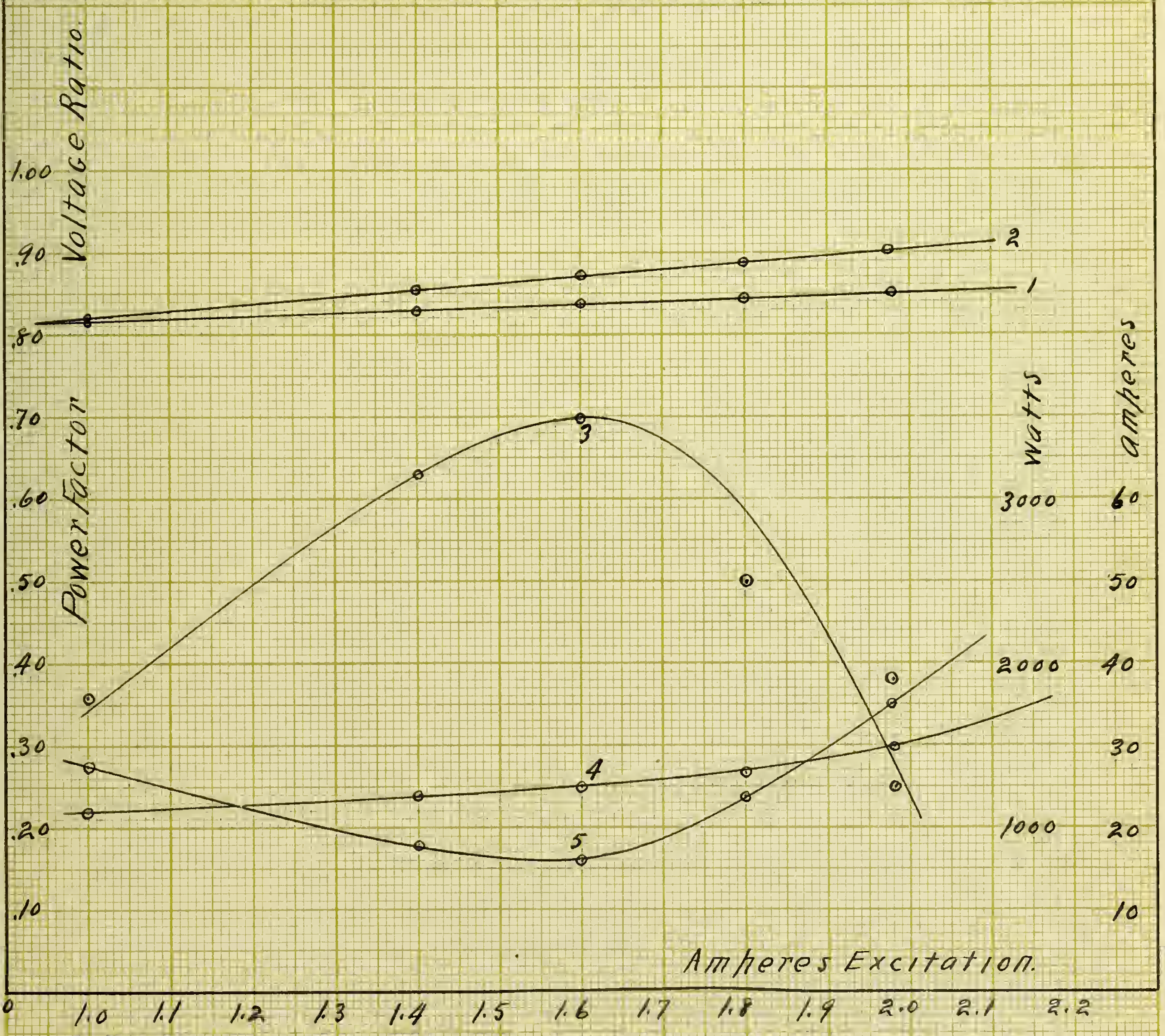
PLATE XXIV.

Experiment No. 3 March 11, 1901.

No Load Curves.

General Electric 7½ K.W. Rotary
One-Three-Phase Transformer.
Inductive Load, Self Excited.
Constant Excitation, Variable Load



Curve 1, Voltage Ratio, Leg A Output.
Curve 2. " " Leg B "
Curve 3, Power Factor.
Curve 4, Watts Lost, Total.
Curve 5, Amperes Input.

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PIATE XXV.

Experiment No. 3, March 11, 1901.
General Electric 7½ K.W. Rotary
One-Three-Phase Transformer.
Power Factor Curves.
Inductive Load, Self Excited.
Variable Load for Constant Excitation.

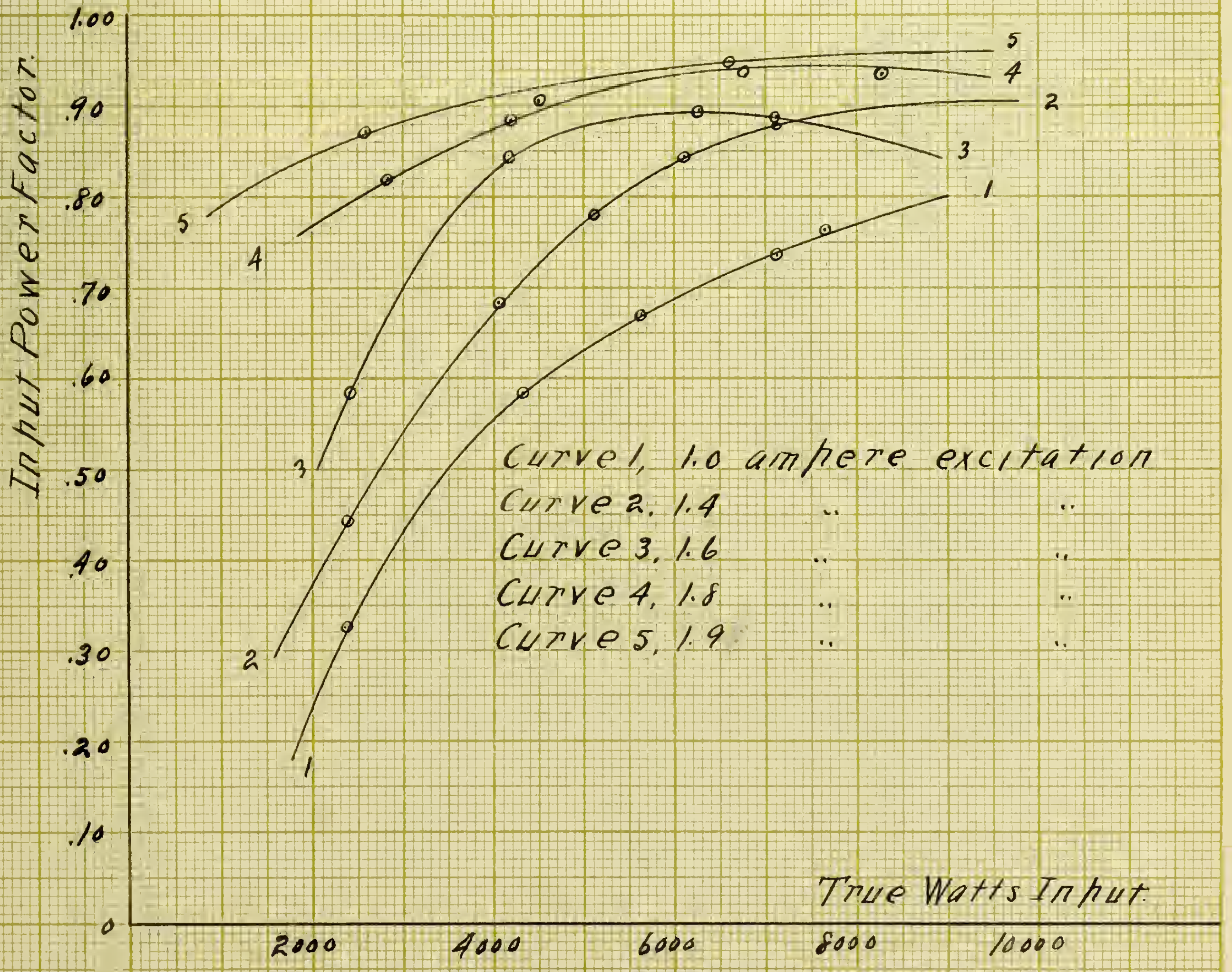

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PLATE XXVI.

General Electric $7\frac{1}{2}$ K.W. Rotary Converter as One to One Phase Transformer. Mechanically Driven. No Field Excitation. Gutmann Experiment (No. 4)

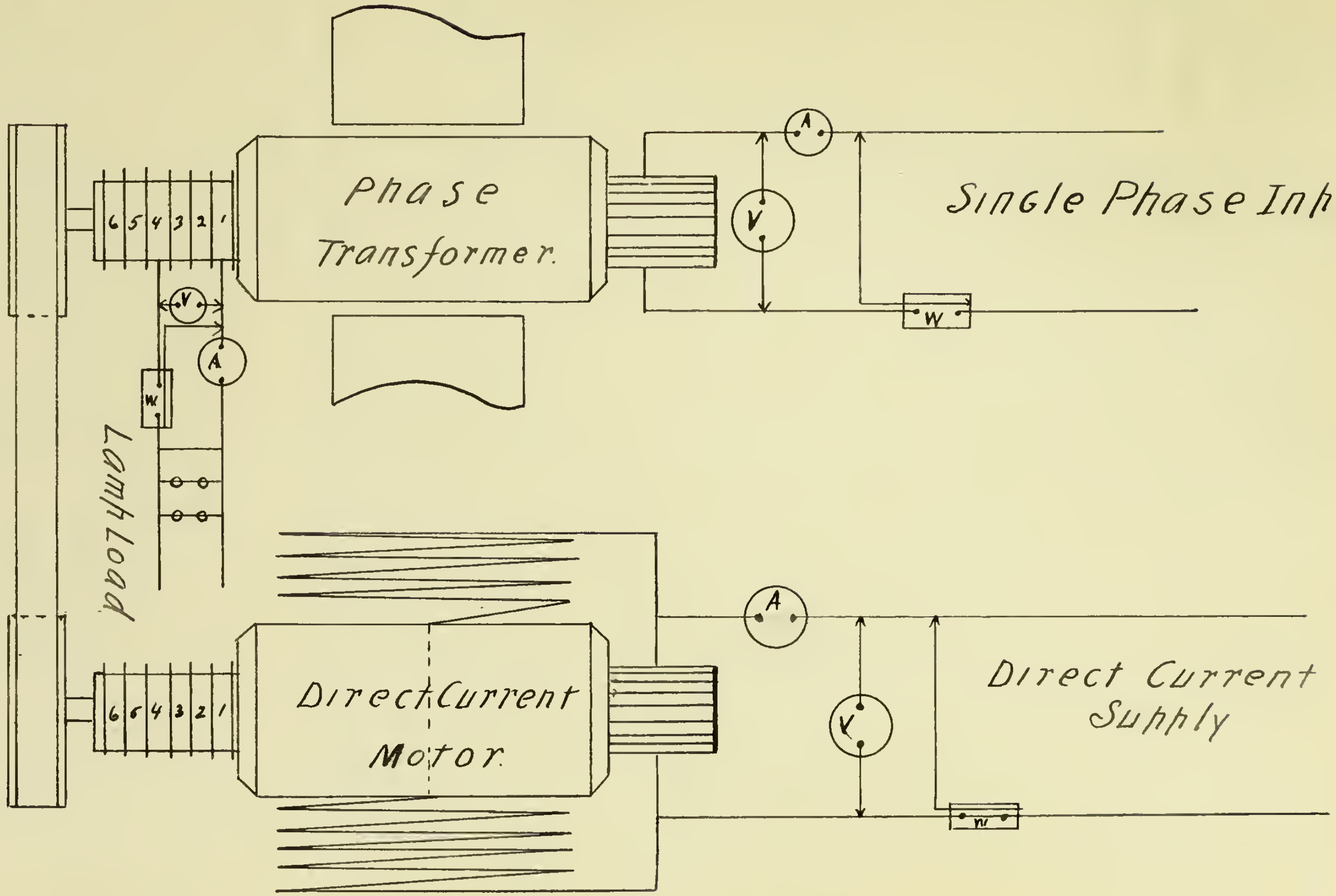

FIG. 37.

less than 76 per cent or greater than 80.3 per cent. The maintained and maximum efficiencies in the one to three-phase transformation are higher than in the one to two-phase transformation.

40. Experiment No. 4. One to One Transformation; GutmannExperiment. In this series single-phase current was applied to the commutator end of the armature of the General Electric rotary and single-phase taken off at the slip rings at the other end. This is a form of the so-called Gutmann Experiment. Mr. Gutmann's plan being ultimately to effect, by similar means, one to three-phase conversion. The latter combination is considered in Experiment No.5, following. The object in operating the machine in this way as a one to one-phase transformer was to deter mine the voltage and current ratios and the efficiency of transformation at several loads and frequencies. In this case the frequency could be altered by varying the speed of the transformer armature. The machine was mechanically driven by the other General Electric rotary. The field of the transformer was unexcited though an inappreciable current was induced therein during the operation. A diagram of connections is shown on Plate 26 page 23.

41. It was found in the above example that with a constant input voltage of 40 the output voltage could be varied throughout a wide range above and below the input voltage by corresponding changes of the speed of the transformer armature. A low impressed voltage was used on account of excessive sparking at the commutator brushes as produced by higher voltages. The machine was operated under a small lamp bank load. The following plates of curves show voltage and current ratios and input power-factor for two separarate loads, also the efficiency on true

watts input base for a speed of 2100 R.P.M. which was the highest speed at which the converter was operated:

Plate 27 , Watts lost in Machine.
Plate 27 , True Efficiency
Plate 28 , Input Power Factor.
Plate 29 , Output Power Factor.
Plate 28 , Voltage Ratios.
Plate 28 , Current Ratios.

Plate 29 also shows output voltage and power factor platted on speed base. It will be noticed that the input power factor increases as the speed of frequency is increased. If it were possible to increase the speed at will, a point might be reached where the power factor would be unity. Since the voltage and current increase with the speed their values would be very large for an input power factor of unity.

42. The peculiar shape of the output power factor curves is especially noticeable as shown on Plate 29. It is seen, that as a whole, the power factor increases as the load is increased; but as the speed increases, on the other hand, the power factor increases, reaching a maximum value, then decreases to a minimum value and again increasing to another maximum value, once more decreases. The minimum value of the power factor is determined by producing the two branches of the curve until they intersect. The curves for the different loads are symmetrical with respect to each other and the minimum power factor occurs at a speed of 1600 R.M.P. in each case. As the load increases and the power factor, as a whole increases, the curves flatten out and it is probable that were unity output power factor obtained the break in the middle of the curve would entirely disappear. It

TABLE XI. Experiment 4.

Corrected Observations. General Electric Rotary as One to One Phase Transformer. Gutmann Experiment. Unexcited Field. Variable Load.

Number	INPUT			OUTPUT			
	Weston #2882	Thompson #13469	Weston # 775	Weston #2322	Thompson #14008	Weston # 1060	Tachometer.
	Vm	am	Wm	Vm	am	Wm	R.P.M.
	1	2	3	4	5	6	7
1	40	54.3	430	35.5	0	0	1240
2	40	55.4	440	36.1	0	0	1325
3	40	55	440	37.0	0	0	1380
4	40	55.4	430	38.2	0	0	1475
5	40	55.3	480	39.5	0	0	1580
6	40	55.3	490	40.6	0	0	1680
7	40	55.6	500	42.4	0	0	1790
8	40	56	510	45.3	0	0	1975
9	40	53.7	520	34.4	3.82	100	1275
10	40	54	530	35.0	3.91	120	1325
11	40	54	560	36.3	4.10	130	1475
12	40	54	580	37.5	4.25	130	1575
13	40	54	590	38.8	4.48	140	1650
14	40	54.5	600	40.5	4.64	150	1760
15	40	54.6	600	41.2	4.8	160	1850
16	40	54.8	620	42.5	5.0	180	1950
17	40	54.6	670	43.7	5.14	190	2050
18	40	54.6	710	34.0	10.7	330	1415
19	40	54.7	790	35.8	11.4	370	1590
20	40	54.8	820	37.0	11.9	410	1740
21	40	54.3	840	38.2	12.6	460	1900
22	40	54.5	910	40.8	13.2	510	2100
23	40	57.1	1020	31.5	19.0	580	1375
24	40	57.7	1040	32.3	19.8	620	1500
25	40	58.2	1100	33.6	20.8	640	1650
26	40	59	1150	35.0	22	720	1800
27	40	57.6	1140	35.8	22.5	760	1950
28	40	58	1190	36.8	23.3	780	2100

TABLE XII. Experimen No 4.

Calculated Results.

	1	2	3	4	5	6
Number	App. Watts Input	Input Power Factor	True Efficiency	Volt Ratio	Current Ratio	Average Input Watts
1	2172	0.20	0	0	0	
2	2216	0.20	0	0	0	
3	2200	0.20	0	0	0	
4	2216	0.20	0	0	0	
5	2212	0.216	0	0	0	
6	2212	0.222	0	0	0	
7	2224	0.224	0	0	0	
8	2240	0.228	0	0	0	465
9	2148	0.242	0.192	1.16	14.1	
10	2160	0.245	0.226	1.14	13.8	
11	2160	0.259	0.232	1.10	13.2	
12	2160	0.268	0.224	1.07	12.7	
13	2160	0.273	0.238	1.03	12.0	
14	2180	0.276	0.250	0.99	11.6	
15	2184	0.275	0.266	0.97	11.2	
16	2192	0.283	0.290	0.94	10.8	
17	2184	0.306	0.284	0.916	10.75	585
18	2184	0.324	0.465	1.18	5.1	
19	2188	0.360	0.468	1.12	478	
20	2192	0.374	0.500	1.08	4.58	
21	2172	0.388	0.547	1.04	4.33	
22	2180	0.417	0.560	98	4.13	804
23	2224	0.446	0.570	1.27	3.06	
24	2308	0.452	0.595	1.24	2.92	
25	2328	0.472	0.582	1.19	2.79	
26	2360	0.487	0.625	1.14	2.64	
27	2304	0.496	0.666	1.12	2.58	
28	2320	0.513	0.655	1.09	2.49	1107

TABLE XIII. Experiment No 4

Values to be Platted.

	1	2	3	4	5	6	7	8	9
Number	App. Watts Input	Power Factor Input	True Watts Input	App. Watts Output	Output Power Factor	True Efficiency	Volt Ratio	Current Ratio	R.P.M.
1	2172	20	430	0	0	0	—	—	1240
2	2216	20	440	0	0	0	—	—	1325
3	2200	20	440	0	0	0	—	—	1380
4	2216	20	430	0	0	0	—	—	1475
5	2212	216	480	0	0	0	—	—	1580
6	2212	222	490	0	0	0	—	—	1680
7	2224	224	500	0	0	0	—	—	1790
8	2240	228	510	0	0	0	—	—	1975
9	2148	242	520	131	765	192	1.16	14.1	1275
10	2160	245	530	137	875	226	1.14	13.8	1325
11	2160	259	560	149	875	232	1.10	13.2	1475
12	2160	268	580	159	82	224	1.07	12.7	1575
13	2160	273	590	189	74	238	1.03	12.0	1650
14	2180	276	600	188	80	250	99	11.6	1760
15	2184	275	600	197	813	266	97	11.2	1850
16	2192	283	620	212	85	290	94	10.8	1950
17	2184	306	670	225	845	284	916	10.75	2050
18	2184	324	710	351	94	465	1.18	5.10	1415
19	2188	360	790	408	906	468	1.12	4.78	1590
20	2192	374	820	440	93	500	1.08	4.58	1740
21	2172	388	840	480	96	547	1.04	4.33	1900
22	2180	417	910	540	945	560	98	4.13	2100
23	2284	446	1020	600	97	570	1.27	3.06	1375
24	2308	452	1040	640	97	595	1.24	2.92	1500
25	2328	472	1100	700	915	582	1.19	2.79	1650
26	2360	487	1150	770	935	625	1.14	2.64	1800
27	2304	496	1140	805	945	666	1.12	2.58	1950
28	2320	513	1190	857	91	655	1.09	2.49	2100

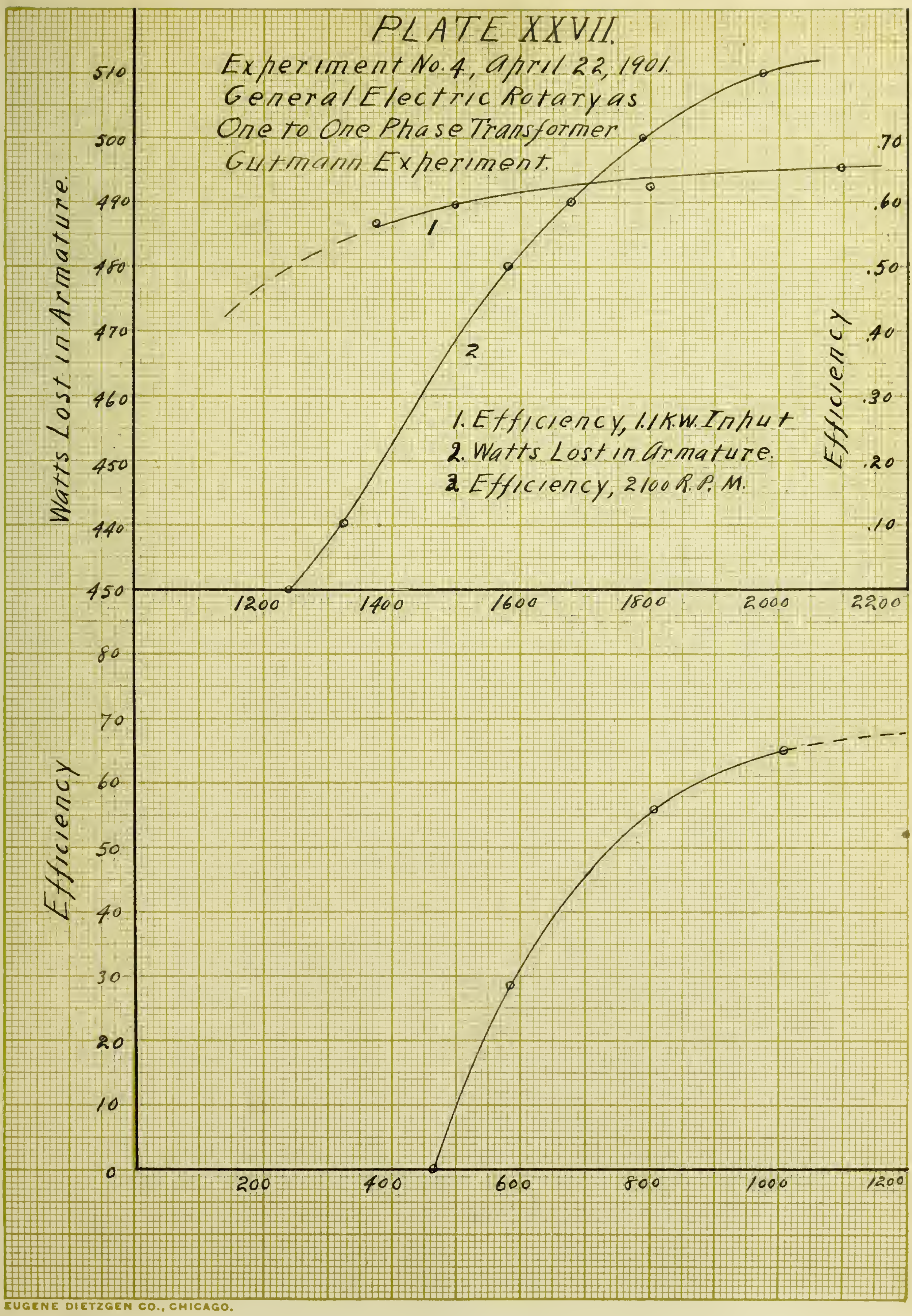

PLATE XXVII.

Experiment No. 4, April 22, 1901.
General Electric Rotary as
One to One Phase Transformer
Gutmann Experiment.

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PLATE XXVIII.

Experiment No. 4 April 22, 1901.
General Electric Rotary as One to One Phase Transformer. Gutmann Experiment.

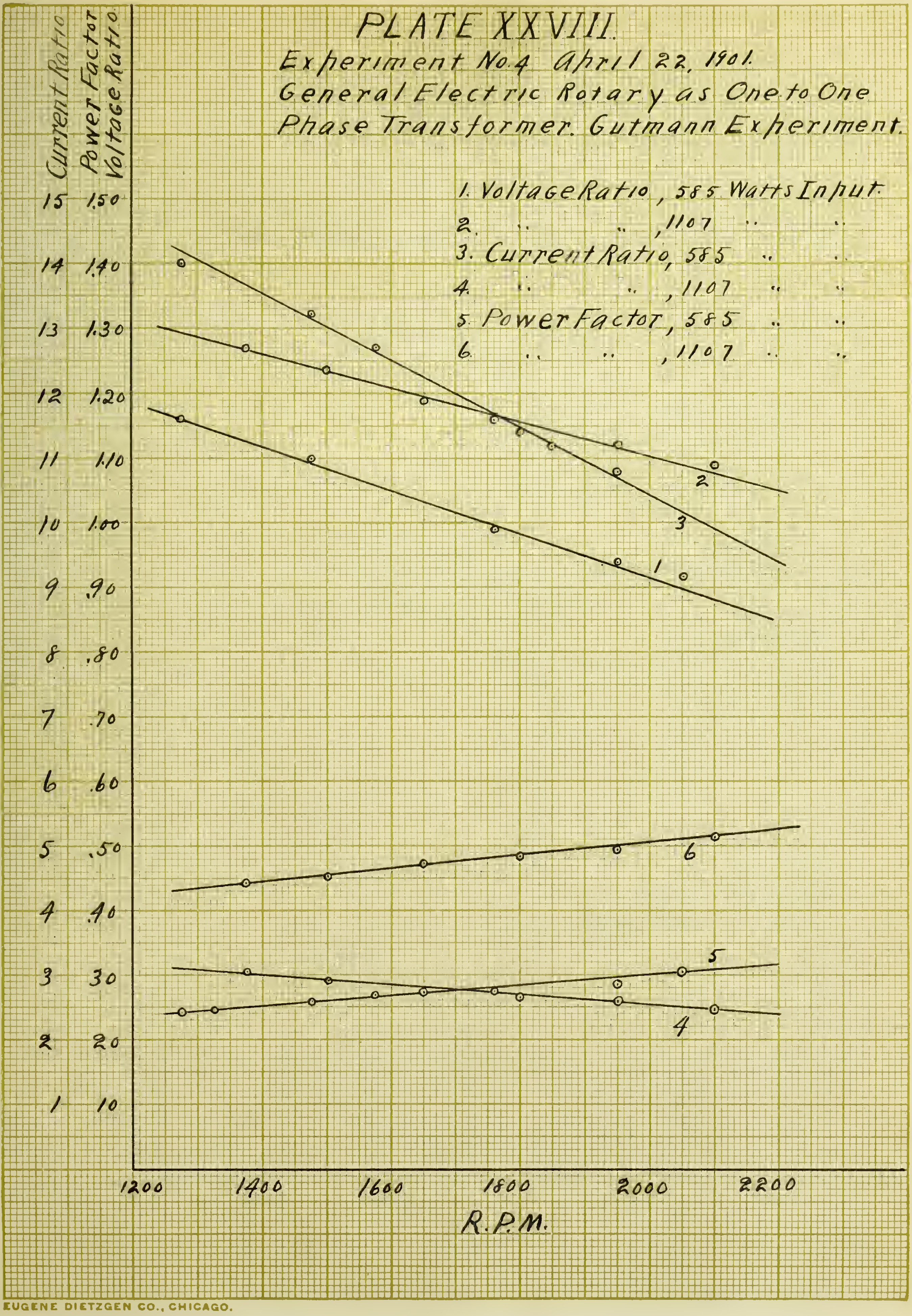

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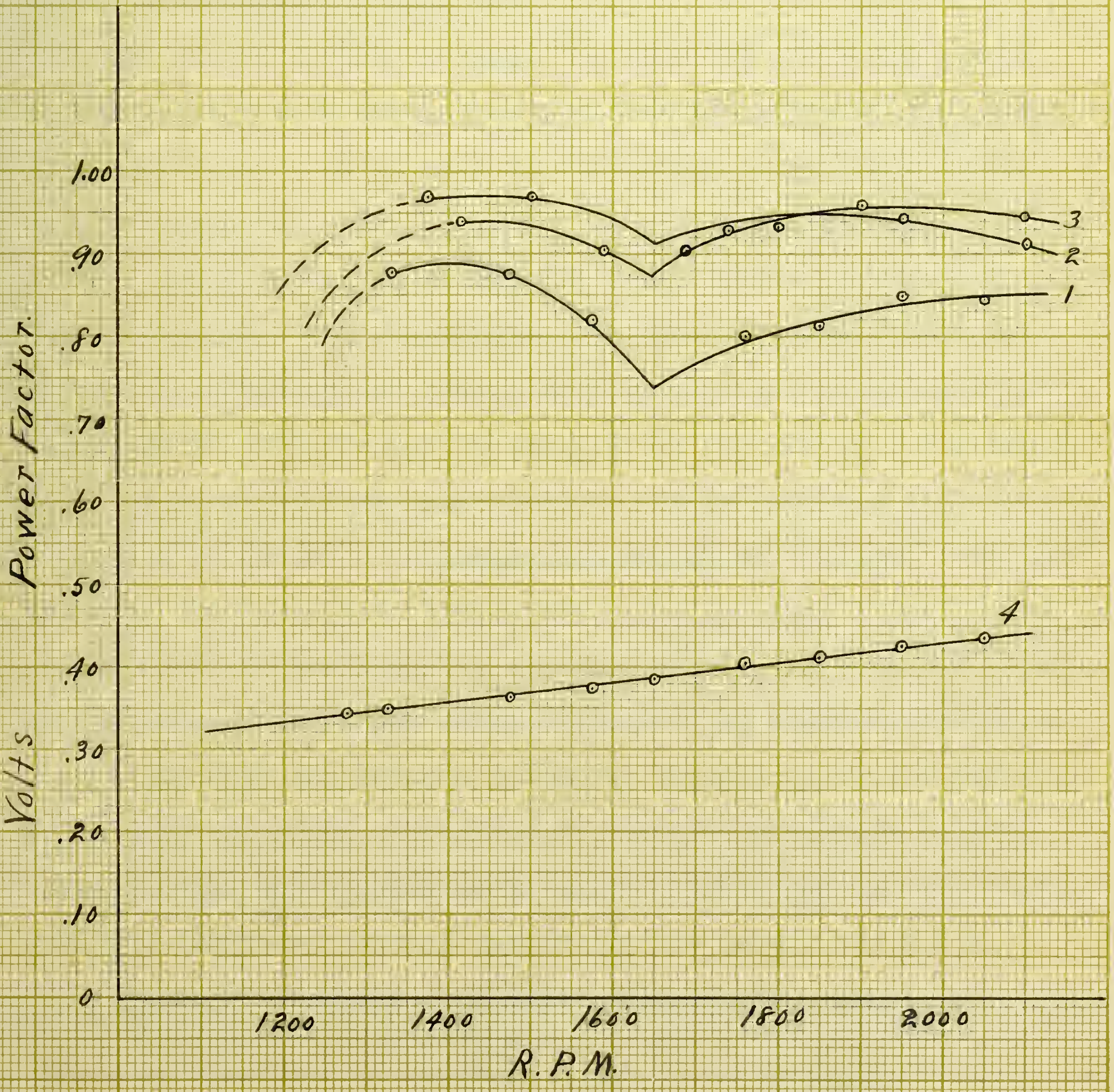
PLATE XXIX.

Experiment No. 4 April 22, 1901
General Electric Rotary as One to One
Phase Transformer. Gutmann Experiment.

{1.
{2. Power Factor Curves, Different Loads.
{3.
4. Output Voltage.



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is also evident that were the speed increased to a sufficiently high point the succeeding indulations in the curve would become smaller and smaller.

43. By means of an oscillograph of the Blondel type, constructed and operated by Mr.E.F.Bracken,[15] some interesting E.M.F.wave forms,taken in connection with the operation of the transformer,were secured. These wave forms or curves may offer an explanation of some of the peculiar features in the operation of the transformer in this way.

The E.M.F. curves are shown on Plate 30 where Curve No.1 is the input E.M.F. wave taken from the Westinghouse O-D potential transformer; Curve No.2 is the actual input E.M.F. curve at the commutator; Curve No.3 is the single-phase output E.M.F. curve. The difference between the three curves is apparent and at the same time remarkable. The rotary converter has the effect of smoothing out Curve No.1 to some extent as shown in No.2, but it is difficult to explain why the output curve should have the peculiar form that it does. It is probable that it is a complex periodic curve though not enough of the wave form was taken to determine this absolutely. The peculiar shape of the output power factor curve is probably due to the combined effect of the output E.M.F. and current curves. An analyses of Curve No.3 shows that the maximum potential rapidly decreases and it is safe to assume that after it reaches a certain minimum point it will again increase in value. These curves were taken when the impressed voltage was 40 and the speed 1200 R.P.M.

44 In getting the true efficiency of the machine as a

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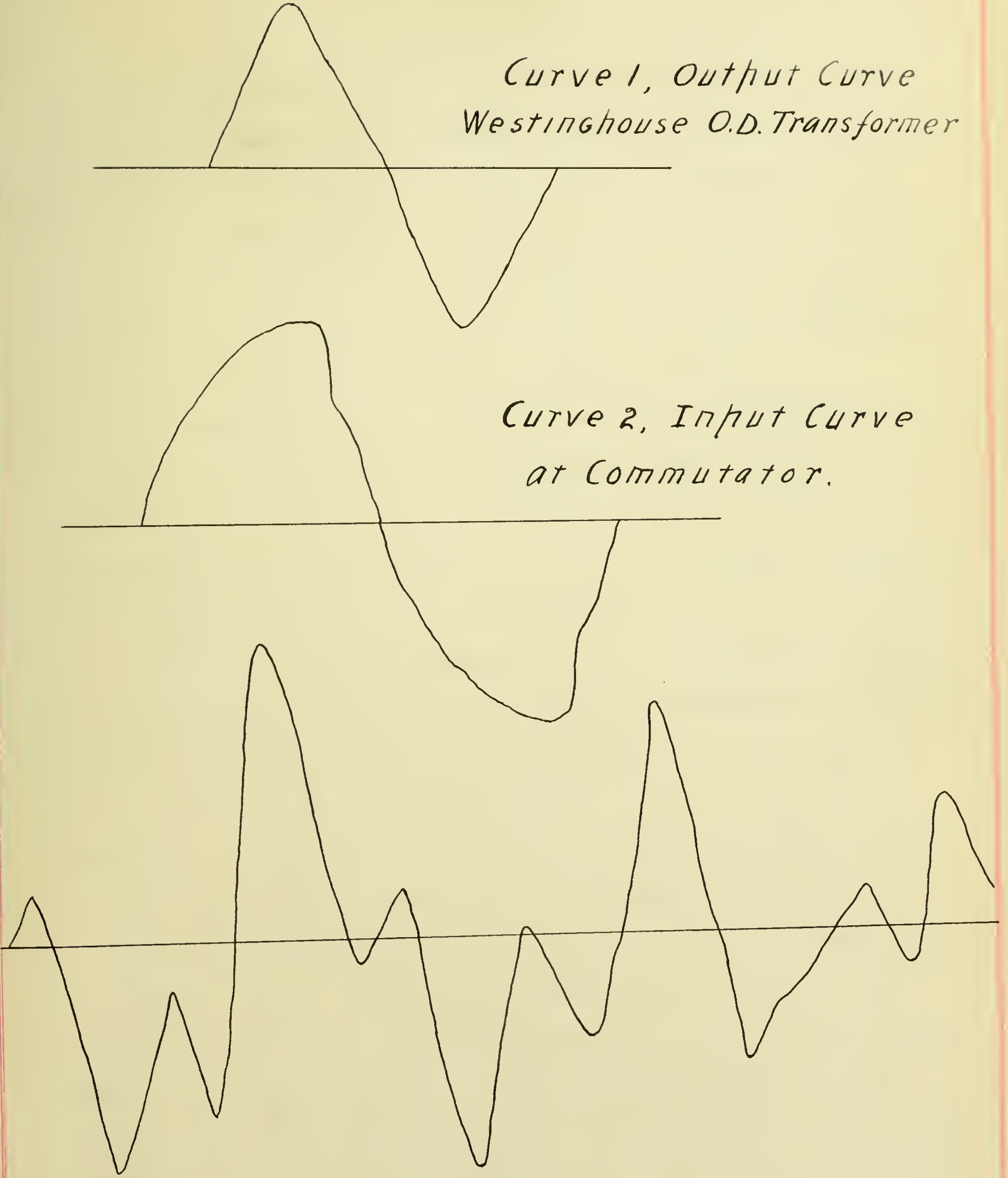
[15] Investigation of the Wave Forms of Alternators and Synchronous Converters by E.F.Bracken,University of Illinois. June 1901

PLATE XXX.



Curve 1, Output Curve
Westinghouse O.D. Transformer

Curve 2, Input Curve
at Commutator.

Curve 3, Output Curve.

phase transformer it would be necessary to measure the mechanical power delivered by the belt from the prime mover, which is in this case the other rotary converter. Hence, the total input into the transformer in watts would be the mechanical input from the belt plus the electric input at the commutator of the rotary transformer. The true efficiency of the transformer is the value of the true output in watts divided by the total input in watts. In the one to one transformation the input of the prime motor was not measured as the principal object of this experiment was to determine voltage and current ratios.

45. Experiment No.5. One to Three-Phase Transformation. The same method of operation was used in this case as in the preceeding experiment. Plate 31 shows a diagram of apparatus and connections. An impressed voltage of 40 was used in this case for the same reason as expressed before.

In order to determine whether or not a three-phase output was actually obtained, a ring-coil, wound three-phase, was connected to the output leads and iron filings sprinkled over a glass plate placed on top of the three-phase coil. The filings immediately arranged themselves along lines characteristic of a three-phase field as shown by the accompanying blue-print.

In this experiment, as in the single-phase transformation, the output voltage varied as the speed of the machine. The transformer was loaded non-inductively by a lamp bank and water rheostat in parallel. Owing to the excessive current in each output circuit, the machine could not be operated at above one half full load, hence the power factor and efficiency curves are somewhat incomplete. The input voltage was kept constant by means of a Westinghouse potential regulator connected to a West-

PLATE XXXI.

Gutmann Experiment (No. 5). General Electric Rotary Converter as One to Three-Phase Transformer.

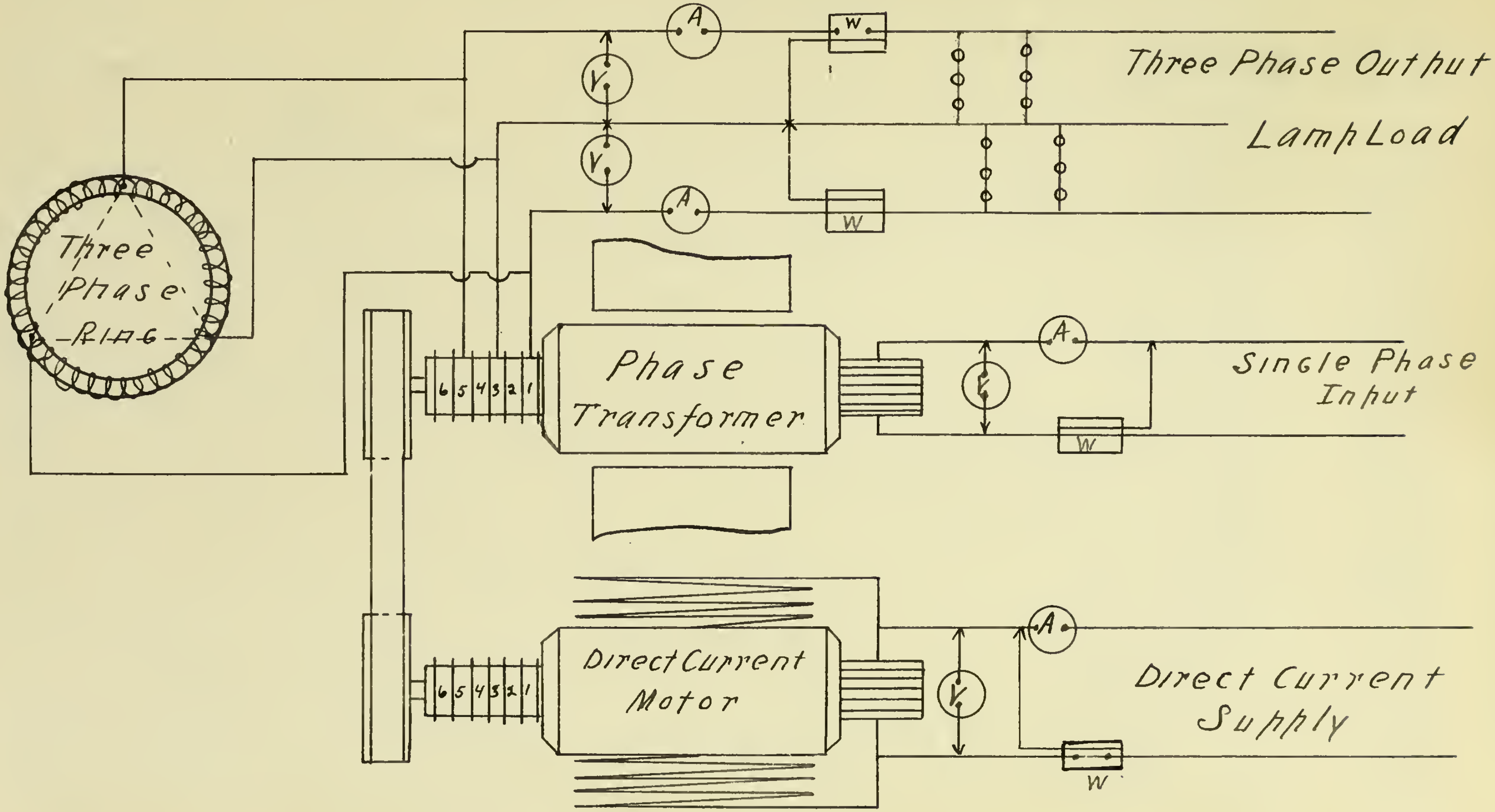


FIG. 38

TABLE XIV. Experiment No 5

Corrected Observations. Gutmann Experiment
General Elect. Rotary, One-Three-Phase Transformer.

Number	INPUT		INPUT			OUTPUT-A			OUTPUT-B			
	West.	Thomp.	West.	thomp.	West	West	thomp	West	west	Thomp	west	
	Vm	am	Vm	am	Wm	Vm	am	Wm	Vm	am	Wm	
	3937	538	2322	13469	775	2931	14108	1060	2882	14010	213	R.P.M.
	1	2	3	4	5	6	7	8	9	10	11	12
1	130	11	40	50	540	28.7	0	0	29	0	0	1200
2	130	12	40	52	545	30.5	0	0	31	0	0	1400
3	131	12.2	40	52	525	32.5	0	0	32.8	0	0	1600
4	130	13.0	40	53	525	35	0	0	35.5	0	0	1800
5	128	14.0	40	54	600	38.7	0	0	38.5	0	0	2000
6	132	14.0	40	52	520	30.3	3	70	29.	3.3	130	1400
7	130	15.0	40	52.8	528	32.5	3.28	80	31	3.6	150	1600
8	131	14.0	40	53	538	35	3.58	100	33.5	3.9	170	1800
9	129	16.0	40	53	545	37	3.76	120	35.5	4.2	180	2000
10	130	16.0	40	53.4	540	30.2	6.1	150	29	4.9	175	1400
11	130	16.5	40	53.2	552	32.7	6.7	190	31	5.37	200	1600
12	131	14.0	40	53	560	34	7.0	200	32.7	5.65	220	1800
13	130	15.0	40	53	569	35.5	7.32	220	33.5	5.85	230	2000
14	134	11.0	40	53	850	29.5	8.8	220	27	9.2	280	1400
15	134	12.5	40	53	870	30.5	9.2	250	27	8.9	275	1500
16	133	12.0	40	53.3	900	31.2	9.4	250	28.5	9.1	300	1600
17	133	13.5	40	53.2	950	33	10.1	300	30	9.8	330	1800
18	129	15.0	40	53.5	1050	35.1	10.9	350	32	10.5	370	2000
19	134	13.0	40	54.3	1020	29.1	12.2	310	26	12.35	350	1400
20	133	14.0	40	54.8	1080	30.7	13.1	370	27	13.2	390	1600
21	130	16.0	40	55.2	1040	32.5	13.9	430	28.5	13.7	440	1800
22	127	15.5	40	54	1160	32.8	15	480	31	9.5	350	2000
23	133	15.0	40	54	1040	34	13.8	425	32	8.6	320	1800
24	132	14.5	40	61.8	1450	27.9	22.3	600	23	21.5	550	1400
25	130	14.5	40	63	1570	29.2	23.8	660	23.5	23	580	1600
26	129	15.5	40	64	1670	30.7	25.5	750	25	25	650	1800
27	127	17.5	40	65.4	1780	31.2	26.9	850	26	26	700	2000

TABLE XV. Experiment No. 5

Calculated Results and Platted Values.

Number	Watts Input South Rotary	Watts Input Transformer	Total True Watts Input	Total App. Watts Input	Total True Watts Output	Input Power Factor	Efficiency System	Volt Ratio A	Volt Ratio B	R.P.M.	Efficiency of Transformer
1	1430	540	1970	2000	0	.27	0	1.35	1.38	1200	0
2	1560	545	2105	2080	0	.262	0	1.31	1.29	1400	0
3	1600	525	1825	2080	0	.252	0	1.23	1.22	1600	0
4	1690	525	2215	2120	0	.248	0	1.14	1.13	1800	0
5	1790	600	2390	2160	0	.278	0	1.04	1.04	2000	0
6	1850	520	2370	2080	200	.25	.085	1.32	1.38	1400	.385
7	1950	528	2478	2112	230	.25	.093	1.23	1.29	1600	.435
8	1824	538	2362	2120	270	.254	.114	1.14	1.19	1800	.58
9	2060	545	2605	2120	300	.257	.115	1.08	1.13	2000	.55
10	2080	540	2620	2136	325	.254	.124	1.32	1.38	1400	.60
11	2018	552	2570	2128	390	.259	.152	1.22	1.29	1600	.71
12	1824	560	2384	2120	420	.264	.176	1.18	1.22	1800	.75
13	1950	569	2519	2120	450	.269	.178	1.13	1.19	2000	.79
14	1474	850	2324	2120	500	.40	.214	1.35	1.48	1400	.59
15	1675	870	2545	2120	525	.41	.206	1.31	1.48	1500	.603
16	1596	900	2496	2132	550	.422	.22	1.28	1.40	1600	.612
17	1800	950	2750	2128	630	.446	.23	1.21	1.29	1800	.664
18	1940	1050	2990	2140	720	.49	.24	1.14	1.25	2000	.685
19	1740	1020	2760	2172	660	.47	.24	1.37	1.54	1400	.648
20	1862	1080	2942	2192	760	.495	.258	1.30	1.48	1600	.704
21	2080	1040	3120	2208	870	.47	.28	1.23	1.40	1800	.836
22	1970	1100	3070	2160	830	.57	.27	1.22	1.29	2000	.755
23	1995	1040	3035	2160	745	.482	.246	1.18	1.25	1800	.717
24	1915	1450	3365	2472	1150	.587	.342	1.43	1.74	1400	.794
25	1890	1570	3460	2520	1240	.624	.359	1.37	1.70	1600	.79
26	2010	1670	3670	2560	1400	.652	.382	1.30	1.60	1800	.84
27	2220	1780	4000	2616	1500	.682	.388	1.25	1.54	2000	.87

PLATE XXXII.

Experiment No. 5 April 24, 1901
General Electric Rotary as One to Three-Phase Transformer. Gutmann Experiment.
Non-inductive Load.

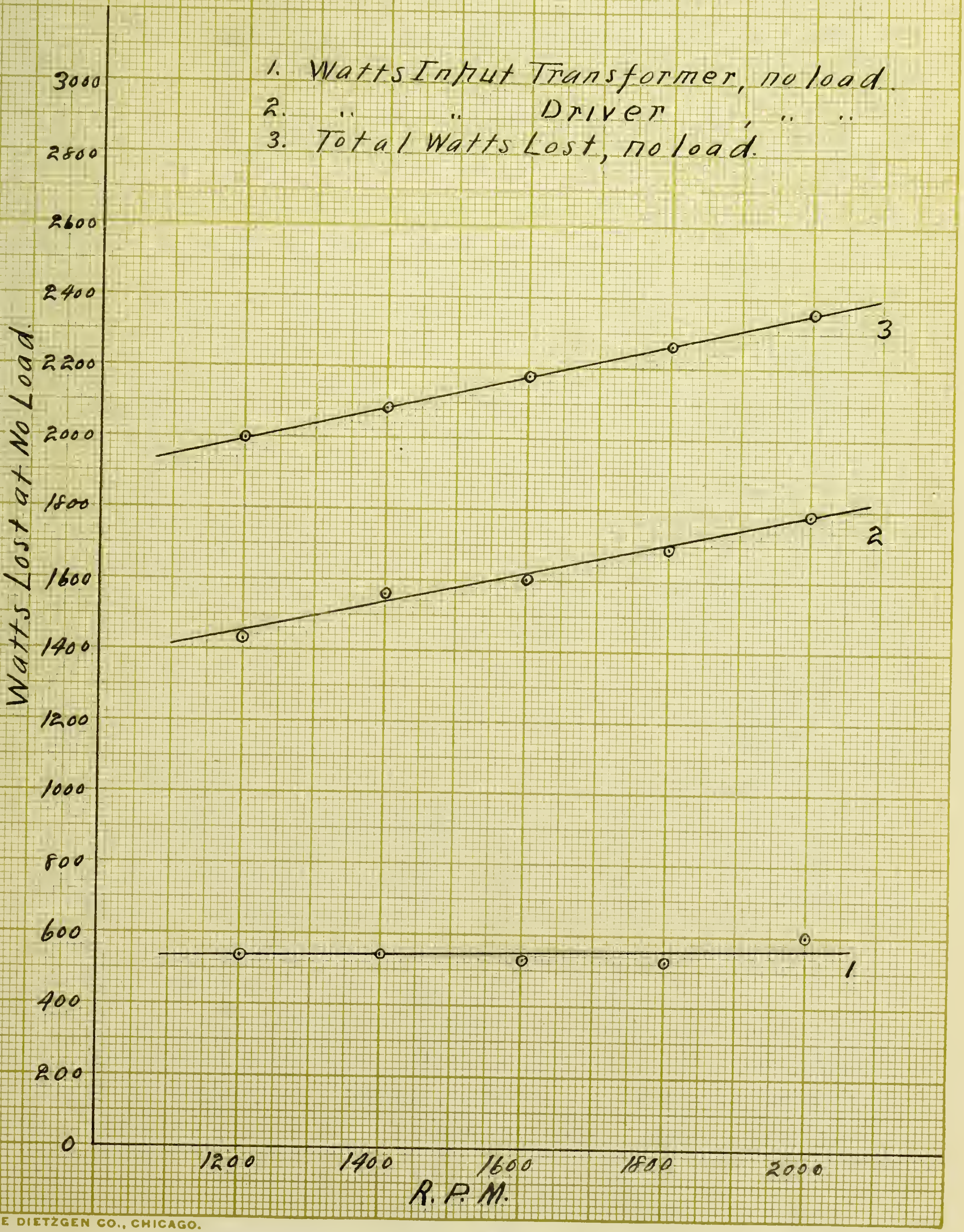


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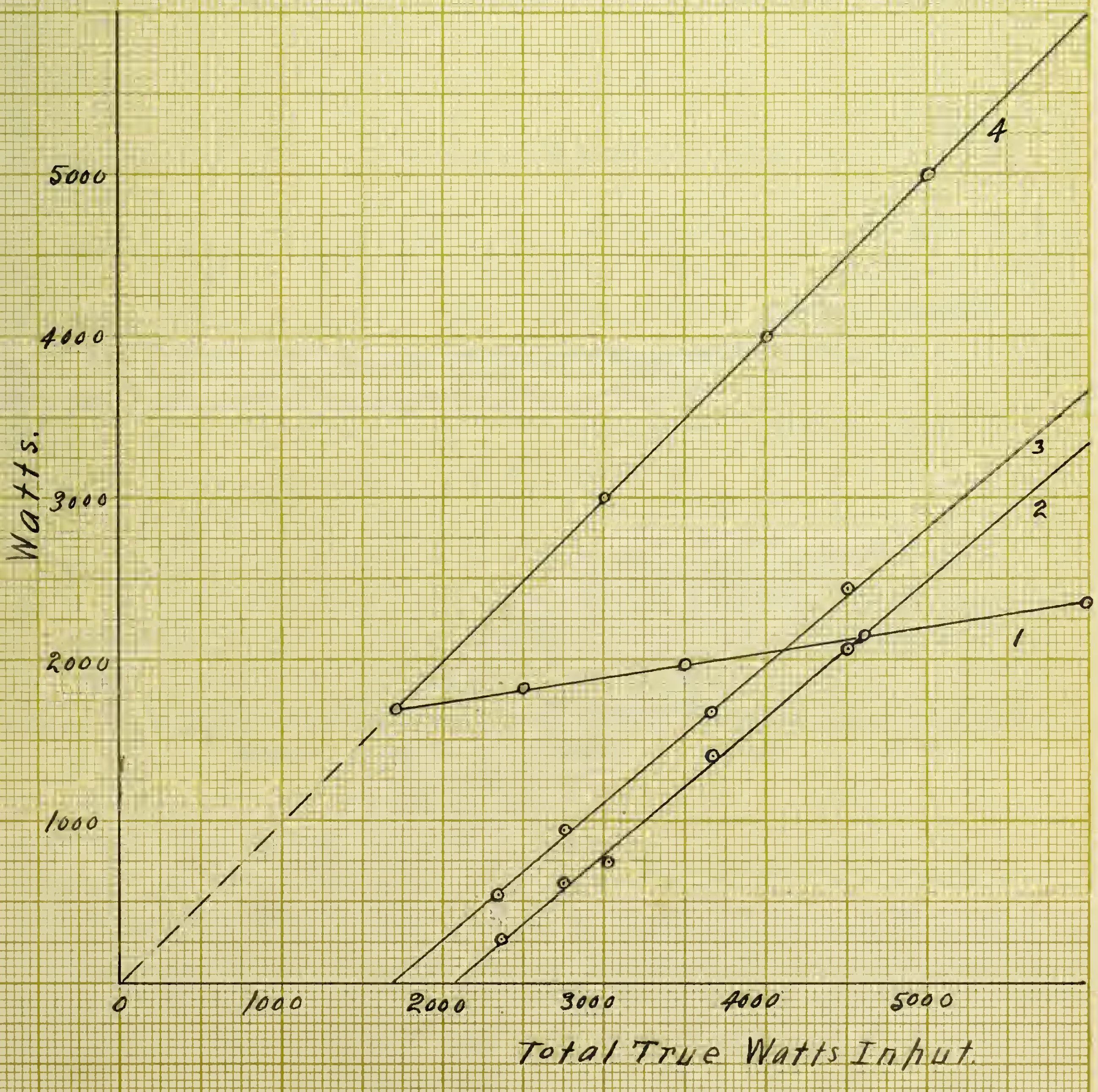
PLATE XXXIII.

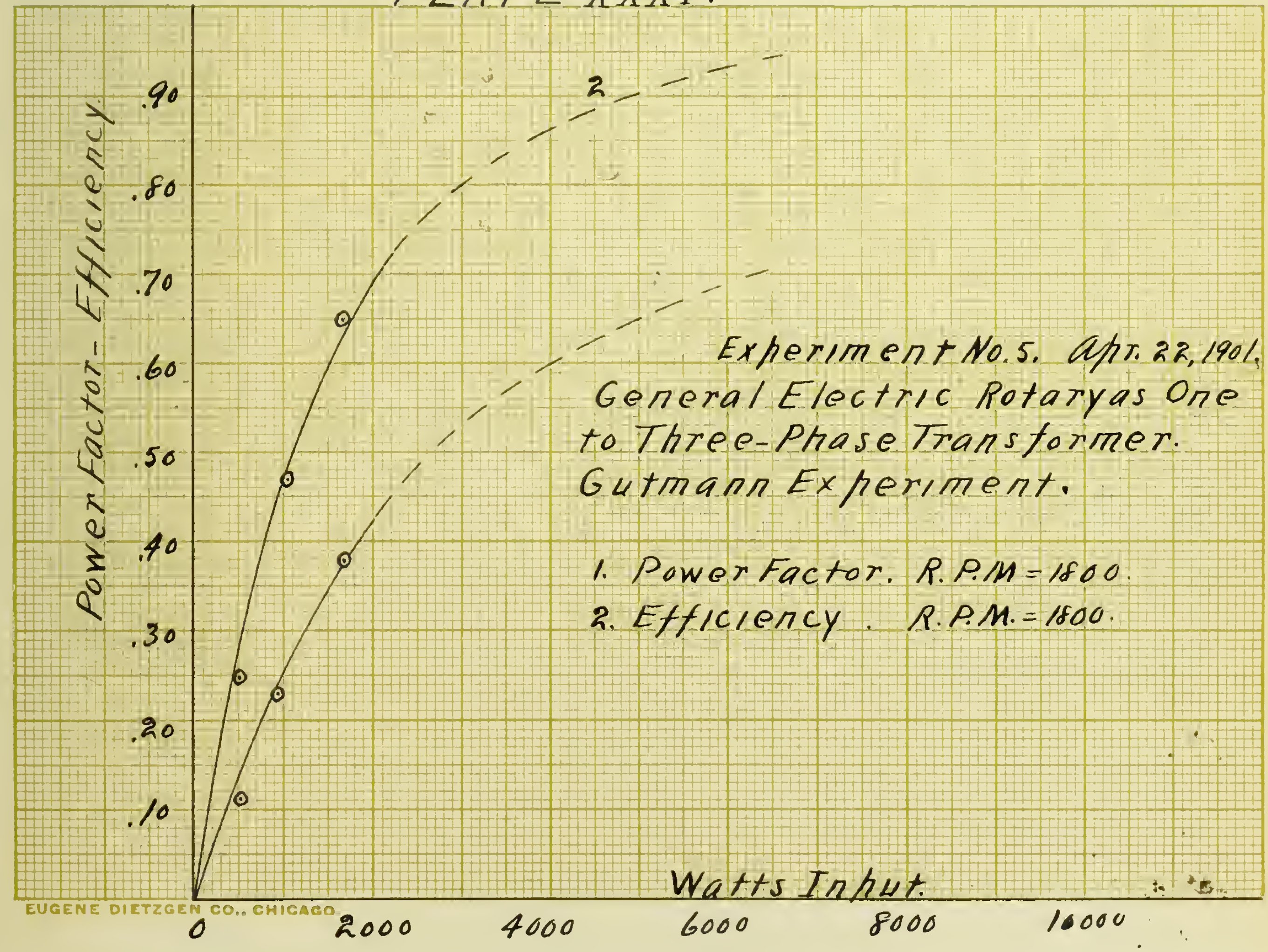
Ouput and Input Watt Curves. 1800 R.P.M.
General Electric Rotary as One-Three-
Phase Transformer. Gutmann Experiment. (5)
Non-inductive Load.

1. Direct Current Input Watts of Driver.
2. Alt. Current Output Watts of Transformer.
3. .. .. Input .. .. ..
4. Total .. ..



EUGENE DIETZGEN CO., CHICAGO.

PLATE XXXIV.



Experiment No. 5. Apr. 22, 1901.
General Electric Rotary as One
to Three-Phase Transformer.
Gutmann Experiment.

1. Power Factor. R.P.M = 1800.
2. Efficiency. R.P.M. = 1800.

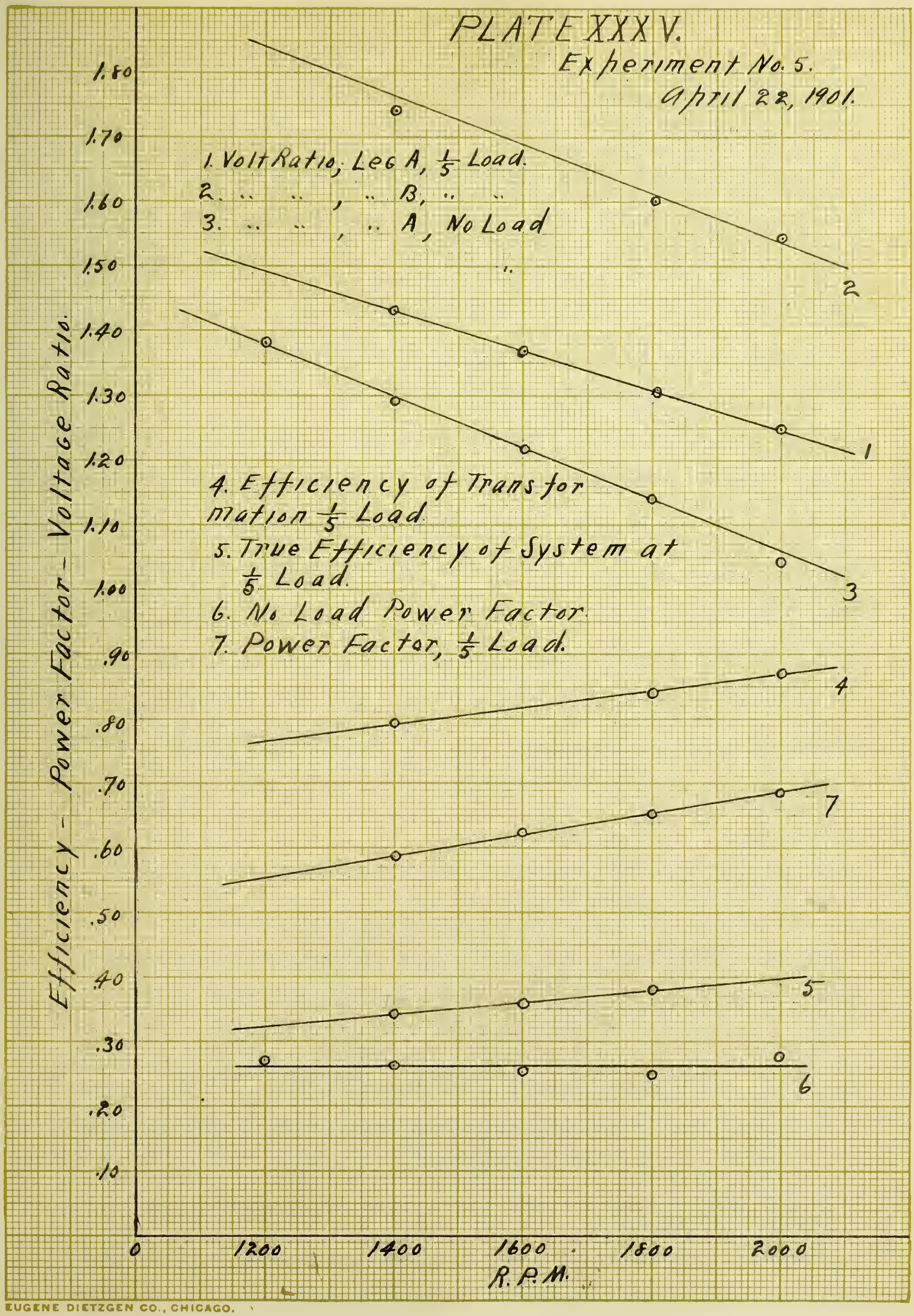


PLATE XXXV.

Experiment No. 5.

April 22, 1901.

EUGENE DIETZGEN CO., CHICAGO.

inghouse O.D. transformer.

The true efficiency of the system includes the energy absorbed by the machine driving the rotary transformer. Curves have been platted showing the true efficiency of transformation at no load output and about 1/5 full load output. The efficiency of transformation is much greater than the efficiency of the whole system. Curves are also platted on a speed base showing variation with the speed of voltage ratio and watts lost at no load. Efficiency and power factor curves, alternating current input, direct current input, total input and alternating current output in watts have been platted on total watts input base. The normal speed of the converter is 1800 R.P.M.

From an examination of Plate 35 it will be seen that the voltage ratio does not reach unity in any case but if the speed were increased sufficiently the voltage ratio would be much less than unity and unity power factor might be obtained. It should be noted that the no load power factor curve is practically a straight line with no effective increase or decrease in value.

46. Experiment No.6. Two to Three Phase Transformation.-- It was attempted to operate the rotary converter as a two to three-phase transformer by disconnecting the brushes at the commutator end of the armature and supplying one-phase to each set of brushes. In testing the output circuits with the three-phase ring coil before mentioned, a weak three-phase field was secured. This field was found to be due to the generation of three-phase currents in the armature due to the residual magnetism in the field coils. The field coils were unexcited. With 110 volts pressure and a current of 20 amperes input in each of the two-phase circuits, no appreciable voltage or current

was obtainable at the alternating current side. Both a Cardew hot-wire voltmeter and a Weston voltmeter were used to detect the voltage, if any. During the operation of the machine the sparking at the brushes was excessive.

47. It is to be regretted that no further investigation was made of this method of phase transformation. The single to polyphase operations were, experimentally, successful, though the efficiency and power factor of the system were very low. For commercial work this method of phase conversion could receive no consideration unless a reliable self starting, efficient machine were constructed. It could not be stated positively that the two to three-phase conversion of phases was impossible in this case as the inability to secure a three-phase output may have been due to some error in connections. At any rate this is a very interesting field for theoretical and experimental investigation.

CHAPTER IX.

APPLICATIONS OF PHASE TRANSFORMERS.

48. General..-- The applications of phase transformers have been indirectly mentioned throughout this paper and very little more need be said concerning their commercial value. As stated in Chapter V. phase transformation has much to do with economical operation of alternating current systems. Especially in the electric transmission and distribution of energy is the phase transformer extremely valuable not only for economical operation but also in regard to the efficiency of the system.

Owing to the imperfection of the single-phase induction motor it has been attempted to construct a one to two-phase or a one to three-phase static transformer, which would operate successfully on single-phase circuits where two and three phase induction motors were used. Although Mr. Bradley succeeded in constructing a transformer which could be adjusted for a true three-phase current at different motor loads, it has not been proven to be commercially successful on account of the imperfection of the condenser. A rotary one to three-phase converter could be used successfully in this case as far as phase transformation is concerned but ~~in this case~~ the first cost of the machine, efficiency, and cost of operation must be figured. ~~upon~~.

There are many power transmission plants where the phase transformer would be considered, at present, to be indispensible.

There is a wide field for the use of phase transformers in the future for polyphase electric railways. In the advent of the perfection of a variable speed polyphase motor for railway work the phase transformer will have an added value in the transmission and distribution of electric energy.

The synchronous phase converter has the double value as a phase transformer and direct current generator at the same time. This enables its installation in places where its use simply as a phase converter or a direct current generator would not be economical.

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